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This report contains a software program for the optimum design of sandwich panels. This program calculates the minimum weight design of sandwich beams and plates subject to stiffness and/or strength constraints. The program has been designed to run on an IBM PC compatible computer. The analysis performed by the program is described together with a complete listing of program. The program is available on diskette which interested users may obtain from Professor Lorna Gibson at MIT.

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OPTIMUM DESIGN METHODS FOR STRUCTURAL SANDWICH PANELS

Final Technical Report

by

Lorna J. Gibson

U. S. ARMY RESEARCH OFFICE

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ANALYSIS AND MINIMUM WEIGHT DESIGN
IN SANDWICH BEAMS WITH RIGID FOAM CORE

I. Introduction

A sandwich beam is shown in Figure 1. It has a span ℓ and a width b. The face and core thicknesses are t and c respectively and the core density is ρ_c. The face material has a density ρ_f, a Young's modulus E_f and a yield strength σ_{yf}. The core has a Young's modulus E_c, a shear modulus G_c, a uniaxial yield strength σ_c^* and a shear strength τ_c^*. The solid from which the core is foamed has a density ρ_s, a Young's modulus E_s and a yield strength σ_{ys}.

In order to simplify the analysis of sandwich beams, the following assumptions are made in this program :

(1) Both the face and core materials are isotropic.

(2) The sandwich beam has an antiplane core and thin faces.

(3) The beam is narrow, so that normal stresses in the y direction can be neglected.

(4) Ordinary beam theory is valid for the sandwich beam.

The foam core property-density relationships are

$$E_c = C_3 \left(\rho_c / \rho_s \right)^A E_s$$

$$\tau_c^* = C_4 \left(\rho_c / \rho_s \right)^B \sigma_{ys}$$

$$G_c = C_8 \left(\rho_c / \rho_s \right)^G E_s$$

where C_3, C_4, C_8, A, B and G are material properties.

For a sandwich beam, the maximum moment is given by

$$M = \frac{P\ell}{C_1}$$

The maximum shear force in the beam is

$$V = \frac{P}{C_2}$$

The maximum deflection due to bending and shearing stresses can be expressed as

$$\Delta = \Delta_b + \Delta_s$$

$$= \frac{P\ell^3}{C_5 D} + \frac{P\ell}{C_6 A_s G_c}$$

where C_1, C_2, C_5 and C_6 are constants related to the loading geometry.

$$D = E_f \frac{bt^3}{6} + E_f \frac{btd^2}{2} + E_c \frac{bc^3}{12}$$

$$A_s = \frac{bd^2}{c}$$

$$d = c + t$$

Figure 2 shows the load constants for six different loading configurations which are available in this program.

The program has four parts :

(1) Analysis of sandwich beam deflections and stresses.

(2) Minimum weight design of a sandwich beam for stiffness.

(3) Minimum weight design of a sandwich beam for strength.

(4) Minimum weight design of a sandwich beam for both stiffness and strength.

II. Analysis of Sandwich Beam

The critical normal and shear stresses in the face material are

$$\sigma_f = \frac{Mz}{D} E_f \qquad (c/2 \le z \le h/2 \; ; \; -h/2 \le z \le -c/2)$$

$$\tau_f = \frac{V}{D} E_f \left[\frac{((c/2)+t)^2 - z^2}{2} \right]$$

The critical normal and shear stresses in the core are

$$\sigma_c = \frac{Mz}{D} E_c \qquad (-c/2 \le z \le c/2)$$

$$\tau_c = \frac{V}{D} \left[E_f \frac{td}{2} + \frac{E_c}{2} \left(\frac{c^2}{4} - z^2 \right) \right]$$

The maximum deflection in the beam is

$$\Delta = \frac{P\ell^3}{C_5 D} + \frac{P\ell}{C_6 A_e G_c}$$

Note that the location of applied force can be arbitrary in the analysis of sandwich beam.

The failure equations for the sandwich beam are :

Face yielding :

$$P_{fy} = C_1 \sigma_{yf} bct/\ell$$

Face wrinkling :

$$P_{fw} = 0.57 C_1 C_3^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c/\rho_s)^{2A/3} bct/\ell$$

Core shearing :

$$P_{cs} = \frac{C_4(\rho_c/\rho_s)^B \sigma_{ys} bc}{\left(\left[\dfrac{C_3(\rho_c/\rho_s)^A E_s}{2C_1(t/\ell)E_f} \right]^2 + \left(\dfrac{1}{C_2} \right)^2 \right)^{1/2}}$$

This program will make a comparison of P_{fy}, P_{fw}, P_{cs} and pick one critical loading, then check whether the stress state is safe or not.

III. Minimum Weight Design for Stiffness in Sandwich Beams

The maximum deflection of the sandwich beam is

$$\Delta = \frac{P\ell^3}{C_5 D} + \frac{P\ell}{C_6 A_s G_c}$$

Solving for the density of the core, we obtain

$$\rho_c = \left[\frac{1}{C_8} \frac{C_5}{C_6} \frac{E_f}{E_s} \frac{P\ell tc}{(\Delta C_5 btc^2 E_f - 2P\ell^3)} \right]^{1/G} \rho_s$$

The weight of the sandwich beam is

$$W = 2\rho_f b\ell t + \rho_c b\ell c$$

$$= 2\rho_f bt\ell + \left[\frac{1}{C_8} \frac{C_5}{C_6} \frac{E_f}{E_s} P\ell^{(1+G)} tc^{(1+G)} b^G \right]^{1/G} \rho_s$$

$$\left[\Delta C_5 btc^2 E_f - 2P\ell^3 \right]^{-1/G}$$

Letting $\partial W/\partial t = 0$ and $\partial W/\partial c = 0$ and solving, we find that

$$c_{opt} = \left\{ 4\left[\frac{G}{G-1}\left(\frac{4}{G-1}\right)^{1/G}\right]\left(\frac{2+2G}{G-1}\right)^{1-1/G}\frac{\rho_f}{\rho_s}\right.$$

$$\left.\left(\frac{\ell C_5 P E_f}{C_s C_6 E_s}\right)^{-1/G} P\ell^3\left(\frac{1}{\Delta C_5 b E_f}\right)^{1-1/G}\right\}^{G/(3G-1)}$$

$$t_{opt} = \frac{2(1+G)P\ell^3}{(G-1)\Delta C_5 E_f b c_{opt}^2}$$

$$(\rho_c)_{opt} = \rho_s\left[\frac{\ell C_5 P E_f t_{opt} c_{opt}}{C_s C_6 E_s(\Delta C_5 E_f b t_{opt} c_{opt}^2 - 2P\ell^3)}\right]^{1/G}$$

Also, we can calculate the nondimensional parameter which gives a measure of the relative face and core stiffnesses.

$$\theta = \frac{\ell}{c_{opt}}\left(\frac{C_s(\rho_c/\rho_s)^G_{opt}E_s}{2E_f}\,\frac{c_{opt}}{t_{opt}}\left(1+3\frac{c_{opt}^2}{t_{opt}^2}\right)\right)^{1/2}$$

Allen suggests that θ should be greater than 20 to ensure that shear lag does not occur.

IV. Minimum Weight Design for Strength in Sandwich Beams

There are three possible failure modes considered in this program. For each case, the critical loading can be calculated

Face yielding :

$$P_{fy} = C_1 \sigma_{yf} bct/\ell$$

Face wrinkling :

$$P_{fw} = 0.57 C_1 C_3^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c / \rho_s)^{2A/3} bct/\ell$$

Core shearing :

Assuming $\sigma_c << \tau_c$

$$P_{cs} = C_2 C_4 \sigma_{ys} (\rho_c / \rho_s)^{B} bc$$

The transition equation between two failure modes can be found by equating the corresponding applied forces.

Face yielding-Face wrinkling :

$$P_{fy} = P_{fw}$$

$$\Longrightarrow \quad \rho_c / \rho_s = \left(\frac{\sigma_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2A}$$

Face yielding-Core shearing :

$$P_{fy} = P_{cs}$$

$$\Longrightarrow \quad t/\ell = \frac{C_2 C_4}{C_1} \left(\frac{\rho_c}{\rho_s} \right)^{B} \frac{\sigma_{ys}}{\sigma_{yf}}$$

Face wrinkling-Core shearing :

$$P_{fw} = P_{cs}$$

$$\Longrightarrow \quad t/\ell = \frac{C_2 C_4}{0.57 C_1 C_3^{2/3}} \left(\frac{\rho_c}{\rho_s} \right)^{B-2A/3} \frac{\sigma_{ys}}{E_f^{1/3} E_s^{2/3}}$$

A typical failure mode map is shown in Figure 3.

The optimum design lies on the transition line between two failure modes. There are four possibilities.

(a) Face yielding-Face wrinkling fail simultaneously

$$P_{fy} = C_1 \sigma_{yf} bct/\ell$$

$$\Longrightarrow \quad t = \frac{P\ell}{C_1 \sigma_{yf} bc}$$

$$P_{fw} = 0.57 C_1 C_3^{2/3} E_f^{1/3} E_s^{2/3} (\rho_c/\rho_f)^{2A/3} bct/\ell$$

$$\Longrightarrow \quad \frac{\rho_c}{\rho_s} = \left(\frac{\sigma_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2A}$$

Therefore, the weight function

$$W = 2\rho_f b\ell \left(\frac{P\ell}{C_1 \sigma_{yf} bc} \right) + \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} \rho_s bc\ell$$

where $\alpha = 0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}$

Letting $\partial W/\partial c = 0$, we find

$$c_{opt} = \left[\frac{2\rho_f P\ell \alpha^{3/2A}}{C_1 \rho_s (\sigma_{yf})^{(1+3/2A)} b} \right]^{1/2}$$

$$t_{opt} = \frac{P\ell}{C_1 \sigma_{yf} bc_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{\sigma_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2A} = \text{constant}$$

From the failure mode map, it is realized that there is a

restriction in t/ℓ for the co-occurrence of face yielding and face wrinkling failures.

$$\frac{t_{opt}}{\ell} = \frac{P}{C_1 \sigma_{yf} b c_{opt}} \leq \frac{t}{\ell} = \frac{C_2 C_4}{C_1} (\rho_c/\rho_s)_{opt}^{B} \frac{\sigma_{ys}}{\sigma_{yf}}$$

$$\Longrightarrow \quad \frac{P}{b\ell} \leq \frac{C_2^{\,2} C_4^{\,2}}{C_1} \sigma_{ys}^{\,2} \frac{2\rho_f}{\rho_s \sigma_{yf}} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-3)/2A}$$

<u>(b) Face wrinkling-core shearing fail simultaneously</u>

$$P_{fw} = 0.57 C_1 C_3^{\,2/3} E_f^{\,1/3} E_s^{\,2/3} (\rho_c/\rho_s)^{2A/3} bct/\ell$$

$$\Longrightarrow \quad t = \frac{P\ell}{0.57 C_1 C_3^{\,2/3} E_f^{\,1/3} E_s^{\,2/3} (\rho_c/\rho_s)^{2A/3} bc}$$

$$P_{cs} = C_2 C_4 (\rho_c/\rho_s)^B \sigma_{ys} bc$$

$$\Longrightarrow \quad \rho_c = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} bc} \right)^{1/B}$$

Therefore, the weight function

$$W = 2\rho_f \frac{P\ell^2}{C_1 \alpha (\rho_c/\rho_s)^{2A/3} c} + \rho_s \ell \left(\frac{P}{C_2 C_4 \sigma_{ys}} \right)^{1/B} (bc)^{1-1/B}$$

Letting $\partial W/\partial c = 0$. It is found

$$c_{opt} = \left[\frac{\rho_s (3-3B) C_1 \alpha b}{2\rho_f (2A-3B) P\ell} \left(\frac{P}{C_2 C_4 \sigma_{ys} b} \right)^{(2A+3)/3B} \right]^{3B/(2A-6B+3)}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} bc_{opt}} \right)^{1/B}$$

$$t_{opt} = \frac{P\ell}{C_1 \alpha (\rho_c/\rho_s)_{opt}^{2A/3} bc_{opt}}$$

Similarly, from the failure mode map, there is a restriction in ρ_c/ρ_s for face wrinkling-core shearing failure mode.

i.e.

$$(\rho_c/\rho_s)_{opt} \leq \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore,

$$\frac{P}{b\ell} \leq \frac{2\rho_f (2A-3B) C_2{}^2 C_4{}^2 \sigma_{ys}{}^2}{\rho_s (3-3B) C_1 \alpha} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-2A-3)/2A}$$

(c) Face yielding-core shearing fail simultaneously

$$P_{fy} = C_1 \sigma_{yf} bct/\ell$$

$$\Longrightarrow \quad t = \frac{P\ell}{C_1 \sigma_{yf} bc}$$

$$P_{cs} = C_2 C_4 (\rho_c/\rho_s)^B \sigma_{ys} bc$$

$$\Longrightarrow \quad \rho_c = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} bc} \right)^{1/B}$$

Thus, the weight function is :

$$W = \frac{2\rho_f P \ell^2}{C_1 \sigma_{yf} c} + \left(\frac{P}{C_2 C_4 \sigma_{ys}}\right)^{1/B} (bc)^{1-1/B} \rho_s \ell$$

Letting $\partial W/\partial c = 0$. We can find

$$c_{opt} = \left[\frac{2\rho_f B P \ell}{\rho_s (B-1) b C_1 \sigma_{yf}} \left(\frac{C_2 C_4 \sigma_{ys} b}{P}\right)^{1/B}\right]^{B/(2B-1)}$$

$$t_{opt} = \frac{P\ell}{C_1 \sigma_{yf} b c_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{P}{C_2 C_4 \sigma_{ys} b c_{opt}}\right)^{1/B}$$

In order for face yielding and core shearing to occur at the same time there is a limitation in ρ_c/ρ_s according to the failure mode map. That is

$$(\rho_c/\rho_s)_{opt} \geq \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha}\right)^{3/2A}$$

Therefore,

$$\frac{P}{b\ell} \geq \frac{2\rho_f B C_2^2 C_4^2 \sigma_{ys}^2}{\rho_s (B-1) C_1 \sigma_{yf}} \left(\frac{\sigma_{yf}}{\alpha}\right)^{(6B-3)/2A}$$

(d) Face yielding-face wrinkling -core shearing fail simultaneously

$$P_{fy} = C_1 \sigma_{yf} bct/\ell$$

$$P_{fw} = C_1 \alpha (\rho_c/\rho_s)^{2A/3} bct/\ell$$

$$P_{cs} = C_2 C_4 \sigma_{ys} (\rho_c/\rho_s)^B bc$$

The three equations in three unknowns give :

$$c_{opt} = \frac{P}{C_2 C_4 \sigma_{ys} b} \left(\frac{\sigma_{yf}}{\alpha} \right)^{-3B/2A} = \text{constant}$$

$$t_{opt} = \frac{P\ell}{C_1 \sigma_{yf} bc_{opt}} = \text{constant}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} = \text{constant}$$

In running this program, the $P/b\ell$ requirement is checked first. The optimal design is evaluated for each case for which the condition is met. Among the above possible failure modes, the one with the minimum weight is selected as the overall optimum design.

V. Minimum Weight Design for Both Stiffness and Strength

In practice, the minimum weight design should take both stiffness and strength requirements into account. In this program, there are three kinds of failure mode considered for sandwich beams.

(a) Stiffness and face yielding failure

$$P_{fy} = C_1 \sigma_{yf} bct/\ell$$

$$\Longrightarrow \quad c = \frac{P\ell}{C_1 \sigma_{yf} bt}$$

$$\Delta = \frac{P\ell^3}{C_5 D} + \frac{P\ell}{C_6 A_s G_c}$$

$$\Longrightarrow \quad \rho_c = \left[\frac{C_5 E_f P\ell tc}{C_g C_6 E_s (C_5 \Delta btc^2 E_f - 2P\ell^3)} \right]^{1/G} \rho_s$$

Therefore, the weight function becomes

$$W = 2\rho_f bt\ell + \left[\frac{\Delta C_g C_6 E_s C_1^{(G-1)} \sigma_{yf}^{(G-1)}}{P^G \rho_s^G \ell^{2G}} t^{(G-1)} \right.$$

$$\left. - \frac{2C_g C_6 E_s C_1^{(G+1)} \sigma_{yf}^{(G+1)} b}{C_5 E_f P^{(G+1)} \rho_s^G \ell^{(2G-1)}} t^G \right]^{-1/G}$$

Since the weight of the sandwich beam is a real number, the value in the bracket should be larger than zero. From this observation it is concluded that

$$0 < t < \frac{\Delta C_5 E_f P}{2C_1^2 \sigma_{yf}^2 b\ell}$$

There is a constraint for face yielding failure.

$$(\rho_c/\rho_s)_{opt} \geq \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Within the range, a minimum weight can be found by incrementally increasing t. The corresponding face and core

thicknesses and foam density are the optimal design values.

(b) Stiffness and face wrinkling failure

$$P_{fw} = C_1 \alpha (\rho_c/\rho_s)^{2A/3} bct/\ell$$

$$\Longrightarrow \quad t = \frac{P\ell}{C_1 \alpha bc} (\rho_c/\rho_s)^{-2A/3}$$

$$\Delta = \frac{P\ell^3}{C_5 D} + \frac{P\ell}{C_6 A_e G_c}$$

$$\Longrightarrow \quad c = \frac{2\ell^2 C_1 \alpha}{C_5 \Delta E_f} (\rho_c/\rho_s)^{2A/3} + \frac{P\ell}{C_8 C_6 E_s b\Delta} (\rho_c/\rho_s)^{-G}$$

Thus, the weight function can be expressed as

$$W = \frac{2\rho_f b P\ell^2}{C_1 \alpha} \left[\frac{C_8 C_6 E_s C_5 \Delta E_f (\rho_c/\rho_s)^{-4A/3}}{2\ell^2 C_8 C_6 E_s \alpha C_1 b + C_5 E_f P\ell (\rho_c/\rho_s)^{(-2A-3G)/3}} \right]$$

$$+ \rho_c \ell \left[\frac{2\ell^2 C_8 C_6 E_s C_1 \alpha b + C_5 E_f P\ell (\rho_c/\rho_s)^{(-2A-3G)/3}}{C_8 C_6 E_s C_5 \Delta E_f (\rho_c/\rho_s)^{-2A/3}} \right]$$

From the failure mode map, it is known that there is a limitation in ρ_c/ρ_s for occurrence of face wrinkling.

$$0 < \rho_c/\rho_s \leq \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

There is a constraint for face wrinkling failure.

$$\frac{t}{\ell} \leq \frac{C_2 C_4 \sigma_{ys}}{C_1 \alpha} (\rho_c/\rho_s)^{B-(2A/3)}$$

The value which corresponds to the minimum weight can be found using the same argument as that for the constraints of stiffness and the face yielding failure mode.

(c) Stiffness, face yielding and face wrinkling

$$P_{fy} = C_1 \sigma_{y\ell} bct/\ell$$

$$P_{fw} = C_1 \alpha (\rho_c/\rho_s)^{2A/3} bct/\ell$$

$$\Delta = \frac{P\ell^3}{C_5 D} + \frac{P\ell}{C_6 A_s G_c}$$

The three constraints in three variables can be solved for :

$$(\rho_c/\rho_s)_{opt} = \left(\frac{\sigma_{y\ell}}{\alpha}\right)^{3/2A}$$

$$c_{opt} = \frac{2\ell^2 C_1 \sigma_{y\ell}}{C_5 \Delta E_f} + \frac{P\ell}{C_s C_6 E_s b\Delta}\left(\frac{\sigma_{y\ell}}{\alpha}\right)^{-3G/2A}$$

$$t_{opt} = \frac{P\ell}{C_1 \sigma_{y\ell} bc_{opt}}$$

In running this program, the three failure modes considered above will be compared with each other to determine the overall minimum weight design.

It is noted that the stiffness-core shearing failure mode is not included in this program because it ends up with an impractically large core thickness.

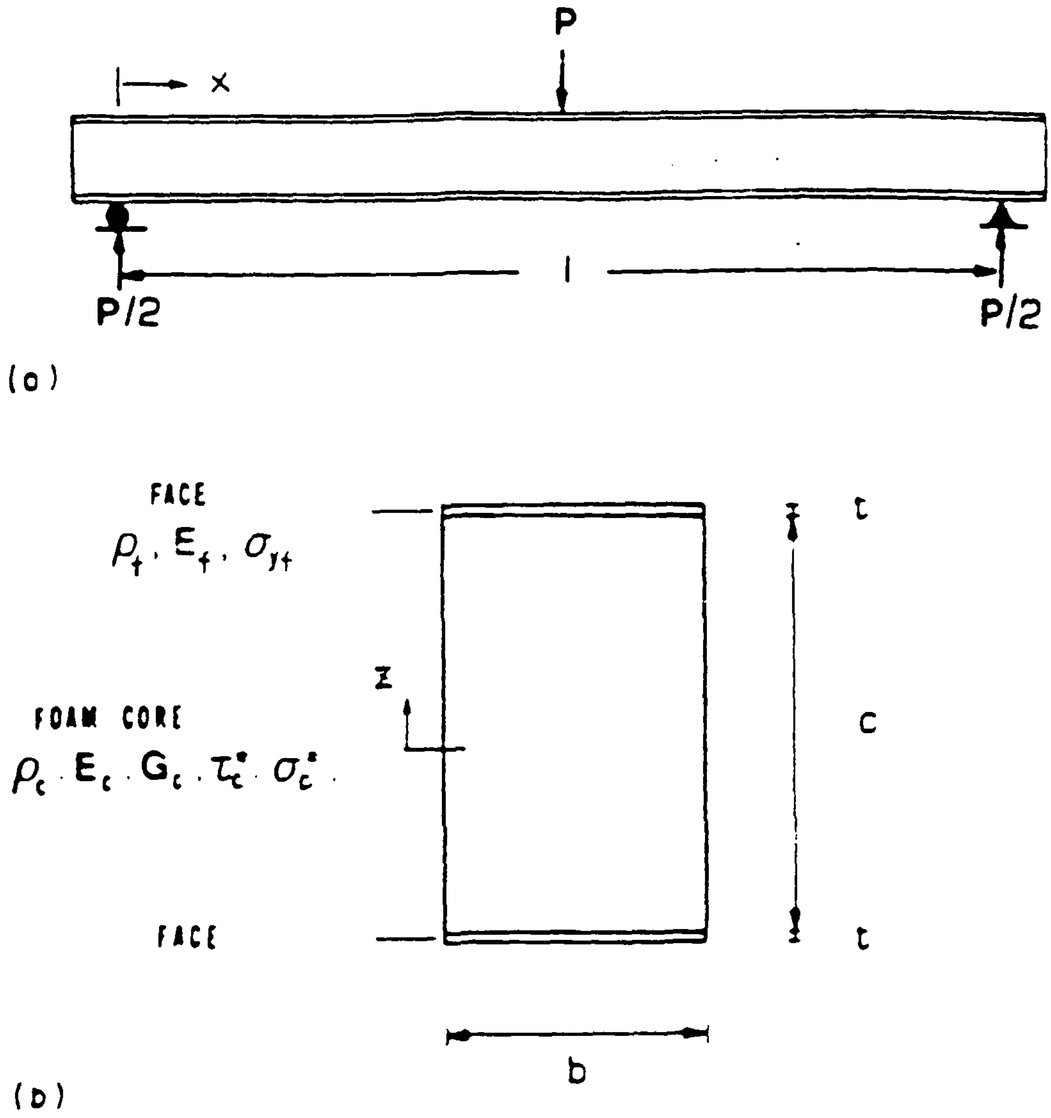


Figure 1. The geometry of the sandwich beam.

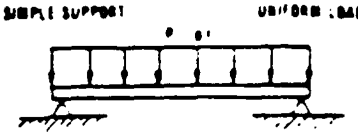
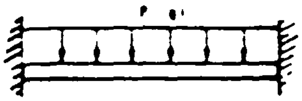
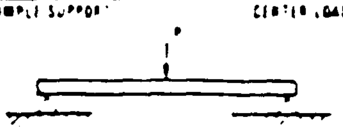
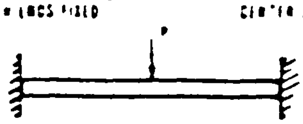
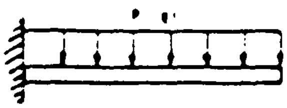
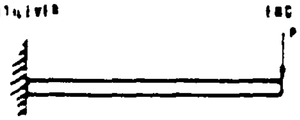
BEAM TYPE	MAXIMUM SHEAR FORCE C_2	MAXIMUM BENDING MOMENT C_1	BENDING DEFLECTION CONSTANT C_5	SHEAR DEFLECTION CONSTANT C_6
SIMPLE SUPPORT UNIFORM LOAD 	2	8	76.8	8
BOTH ENDS FIXED UNIFORM LOAD 	2	12	384	8
SIMPLE SUPPORT CENTER LOAD 	2	4	48	4
BOTH ENDS FIXED CENTER LOAD 	2	8	192	4
CANTILEVER UNIFORM LOAD 	1	2	8	2
CANTILEVER END LOAD 	1	1	3	1

Figure 2. The load constants for different geometry.

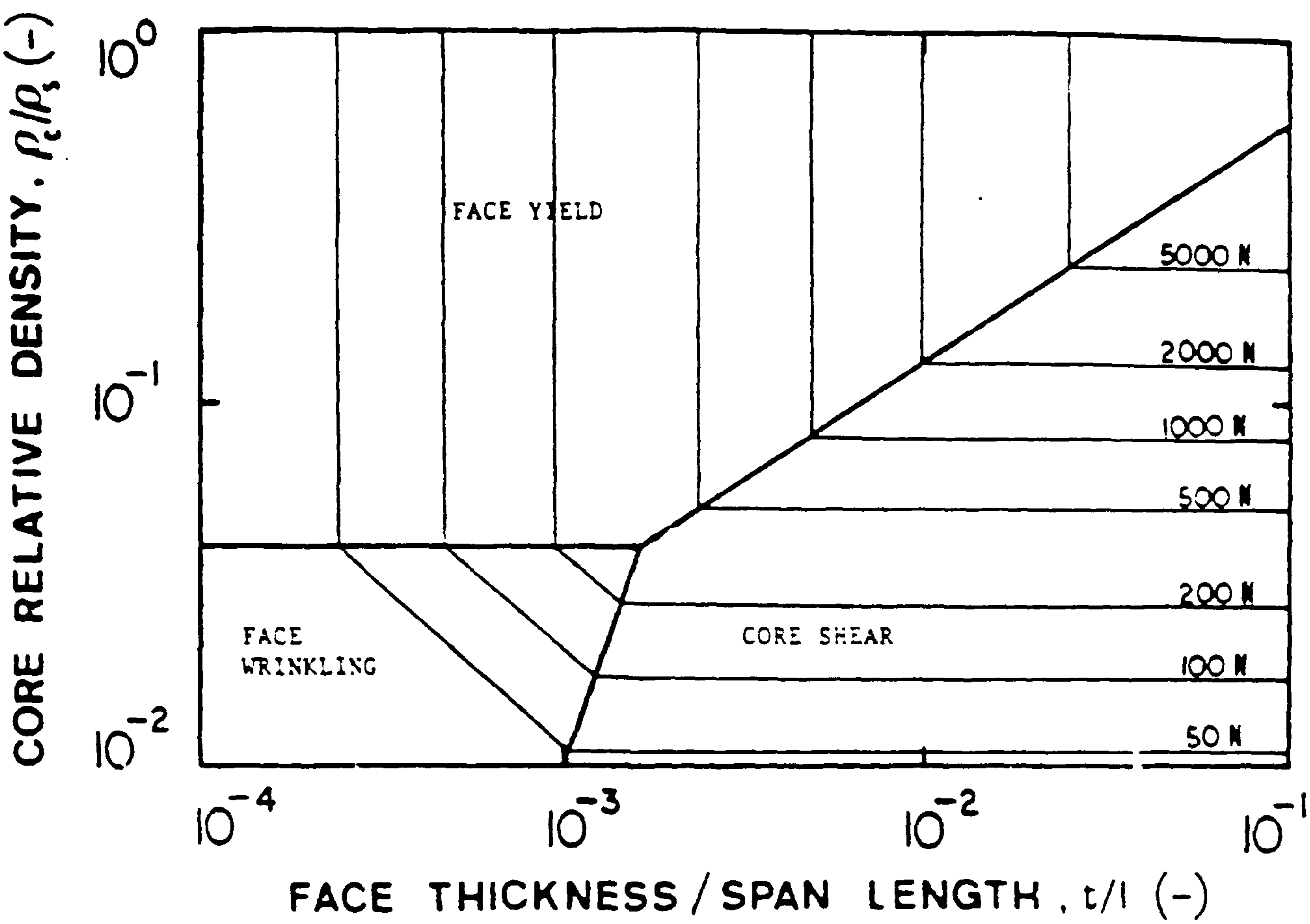


Figure 3. A failure mode map for a sandwich beam loaded in three-point bending with strength contours superimposed on the map (b=c=25 mm).

ANALYSIS AND MINIMUM WEIGHT DESIGN

IN SANDWICH PLATES WITH RIGID FOAM CORE

I. Introduction

There are three kinds of sandwich plate considered in this program :

1. A simply supported circular sandwich plate under a distributed load over a central circular portion of its area.
2. A clamped circular sandwich plate under a distributed load over a central circular portion of its area.
3. A simply supported rectangular sandwich plate under a distributed load over its entire area.

Figure 4 shows a circular sandwich plate which spans a radius r and carries a distributed load q over a central circular portion of its area of radius a. The thickness of each face is t, while that of the foam core is c. The faces have a density ρ_f, a Young's modulus E_f, Poisson's ratio ν_f and a yield strength σ_{yf}. The solid polymer of which the core is made has a density ρ_s, a Young's modulus E_s and a yield strength σ_{ys}. The density of the foamed core is ρ_c, its Young's modulus is E_c, its shear modulus is G_c and its shear strength is τ_c^*.

A rectangular sandwich plate which has a length b and width a (note that $b \geq a$), is shown in Figure 5.

There are three assumptions made in this program :

(1) Both the face and core materials are isotropic.

(2) The sandwich plate has an antiplane core and thin faces.

(3) Stresses in the faces and core in the z-direction are of no importance and neglected.

The foam core property-density relationships are

$$E_c = C_3 \left(\rho_c / \rho_s \right)^A E_s$$

$$\tau_c^* = C_4 \left(\rho_c / \rho_s \right)^B \sigma_{ys}$$

$$G_c = C_g \left(\rho_c / \rho_s \right)^G E_s$$

where C_3, C_4, C_g, A, B and G are material properties.

For a sandwich plate, the maximum deflection can be expressed as

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

The maximum stresses in the face material are

$$\sigma_x \text{ (or } \sigma_r \text{)} = \frac{qa^2}{ct} \left(g_3 + \nu_f g_4 \right)$$

$$\sigma_y \text{ (or } \sigma_t \text{)} = \frac{qa^2}{ct} \left(g_5 + \nu_f g_6 \right)$$

$$\tau_{xy} \text{ (or } \tau_{rt} \text{)} = \frac{qa^2}{ct} \left(1 - \nu_f \right) g_7$$

The maximum stresses in the core are

$$\tau_{xz} \text{ (or } \tau_{rz} \text{)} = \frac{qa}{c} g_8$$

$$\tau_{yz} \text{ (or } \tau_{tz} \text{)} = \frac{qa}{c} g_9$$

where g_1, g_2, g_3, g_4, g_5, g_6, g_7, g_8 and g_9 are constants related to the loading geometry of the sandwich plate.

$$D = \frac{E_f \, t \, c^2}{2 \, (1 - \nu_f^{\,2})}$$

$$S = c \, G_c$$

The loading geometry constants for three different configurations which are available in this program is given in Appendix.

The program has four parts :

(1) Analysis of sandwich plate deflections and stresses.

(2) Minimum weight design of a sandwich plate for stiffness.

(3) Minimum weight design of a sandwich plate for strength.

(4) Minimum weight design of a sandwich plate for both stiffness and strength.

II. Analysis of Sandwich Plate

The maximum stresses in the face material are

$$\sigma_x \text{ (or } \sigma_r \text{)} = \frac{q a^2}{c t} (g_3 + \nu_f g_4)$$

$$\sigma_y \text{ (or } \sigma_t \text{)} = \frac{q a^2}{c t} (g_5 + \nu_f g_6)$$

$$\tau_{xy} \text{ (or } \tau_{rt} \text{)} = \frac{q a^2}{c t} (1 - \nu_f) \, g_7$$

The maximum stresses in the core are

$$\tau_{xz} \; (\text{ or } \tau_{rz} \;) = \frac{qa}{c} g_8$$

$$\tau_{yz} \; (\text{ or } \tau_{tz} \;) = \frac{qa}{c} g_5$$

The maximum deflection in the plate is

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

The failure equations for the sandwich plate are :

Face yielding :

$$q_{fy} = \frac{\sigma_{yf} \; c \; t}{a^2 \; (g_3 + \nu_f g_4 \;)}$$

Face wrinkling :

Plantema pointed out that the superposition of the perpendicular normal stresses in the plane of the face does not affect the wrinkling stress. Therefore,

$$q_{fw} = \frac{\alpha \; c \; t \; (\rho_c / \rho_s)^{2A/3}}{a^2 \; (g_3 + \nu_f g_4 \;)}$$

where $\alpha = 0.57 C_3^{\,2/3} E_f^{\,1/3} E_s^{\,2/3}$

Core shearing :

Assuming $\sigma_c \ll \tau_c$ and the core material is isotropic. Thus,

$$q_{cs} = \frac{C_4 \; (\rho_c / \rho_s)^B \sigma_{ys} c}{a \; g_8}$$

This program will make a comparison of q_{fy}, q_{fw}, q_{cs} and pick

one critical loading, then check whether the stress state is safe or not.

III. Minimum Weight Design for Stiffness in Sandwich Plates

The maximum deflection of the sandwich plate is

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

Since

$$G_c = C_s (\rho_c/\rho_s)^G E_s$$

Solving for the density of the core, it is found

$$\rho_c = \rho_s \left(\frac{a^2 g_2}{4C_s E_s c} \left[\frac{\Delta}{q} - \frac{a^4(1-\nu_f^2) g_1}{8E_f tc^2} \right]^{-1} \right)^{1/G}$$

The weight of the sandwich plate is

$$W = 2\rho_f abt + \rho_c abc \qquad (\text{or } W = 2\rho_f \pi r^2 t + \rho_c \pi r^2 c)$$

Letting $\partial W/\partial t = 0$ and $\partial W/\partial c = 0$ and solving, we find

$$(\rho_c)_{opt} = \rho_s \left(\frac{(G+1)^2(G-1)^2 g_2{}^3 \rho_s E_f}{256 C_s{}^3 G(1-\nu_f{}^2) g_1 \rho_f E_s{}^3} \left(\frac{qa}{\Delta} \right)^2 \right)^{1/(3G-1)}$$

$$c_{opt} = \frac{a}{2} \left(4^{G+1} C_s \frac{G^G (G+1)^{G-1} (1-\nu_f{}^2)^G g_1{}^G \rho_f{}^G E_s}{(G-1)^{2G} g_2 \rho_s{}^G E_f{}^G} \left(\frac{qa}{\Delta} \right)^{G-1} \right)^{\frac{1}{3G-1}}$$

$$t_{opt} = 4a \left(\frac{(G^2-1)^{G+1}(1-\nu_f^{\,2})^{G-1} g_1^{\,G-1} g_2^{\,2} E_f^{\,1-G}}{2^{13G+1} C_s^{\,2} G^{2G} E_s^{\,2}} \right.$$

$$\left. (\rho_s/\rho_f)^{2G} \left(\frac{qa}{\Delta} \right)^{G+1} \right)^{1/(3G-1)}$$

IV. Minimum Weight Design for Strength in Sandwich Plates

Similar to those of the sandwich beams, there are three possible failure modes considered in this program.

Face yielding :

$$q_{fy} = \frac{\sigma_{yf}\ c\ t}{a^2\ (\ g_3 + \nu_f g_4\ )}$$

Face wrinkling :

$$q_{fw} = \frac{\alpha\ c\ t\ (\rho_c/\rho_s)^{2A/3}}{a^2\ (\ g_3 + \nu_f g_4\ )}$$

Core shearing :

$$q_{cs} = \frac{C_4\ \sigma_{ys}\ c\ (\rho_c/\rho_s)^{B}}{a\ g_8}$$

The transition equation between two failure modes can be obtained by equating the corresponding applied distributed forces.

Face yielding-Face wrinkling :

$$q_{fy} = q_{fw}$$

$$\Longrightarrow \quad \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Face yielding-Core shearing :

$$q_{fy} = q_{cs}$$

$$\Longrightarrow \quad t/a = \frac{C_4 \sigma_{ys} (g_3 + \nu_f g_4)(\rho_c/\rho_s)^B}{\sigma_{yf} g_8}$$

Face wrinkling-Core shearing :

$$q_{fw} = q_{cs}$$

$$\Longrightarrow \quad t/a = \frac{C_4 \sigma_{ys} (g_3 + \nu_f g_4)(\rho_c/\rho_s)^{B-2A/3}}{g_8 \alpha}$$

The failure mode map is the same as that of sandwich beams except that the coordinate t/ℓ replaced by t/a.

The optimum design lies on the transition line between two failure modes. There are four possibilites.

(a) Face yielding-Face wrinkling fail simultaneously

$$q_{fy} = \frac{\sigma_{yf} ct}{a^2 (g_3 + \nu_f g_4)}$$

$$\Longrightarrow \quad t = \frac{qa^2 (g_3 + \nu_f g_4)}{\sigma_{yf} c}$$

$$q_{fw} = \frac{\alpha ct (\rho_c/\rho_s)^{2A/3}}{a^2 (g_3 + \nu_f g_4)}$$

$$\Longrightarrow \quad \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore, the weight function becomes

$$W = 2\rho_f abt + \rho_c abc \qquad (\text{ or } W = 2\rho_f \pi r^2 t + \rho_c \pi r^2 c)$$

$$= 2\rho_f ab \frac{qa^2(g_3+\nu_f g_4)}{\sigma_{yf} c} + \rho_s \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} abc$$

Letting $\partial W/\partial c = 0$, we find

$$c_{opt} = \left[\frac{2\rho_f qa^2(g_3+\nu_f g_4)\alpha^{3/2A}}{\rho_s \sigma_{yf}^{(1+3/2A)}} \right]^{1/2}$$

$$t_{opt} = \frac{qa^2(g_3+\nu_f g_4)}{\sigma_{yf} c_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{\sigma_{yf}}{0.57 C_3^{2/3} E_f^{1/3} E_s^{2/3}} \right)^{3/2A} = \text{constant}$$

From the failure mode map, it is realized that there is a restriction in t/a for the co-occurrence of face yielding and face wrinkling failures.

$$\frac{t_{opt}}{a} = \frac{qa(g_3+\nu_f g_4)}{\sigma_{yf} c_{opt}} \leq \frac{t}{a} = \frac{C_4(g_3+\nu_f g_4)}{g_8} (\rho_c/\rho_s)_{opt}^{B} \frac{\sigma_{ys}}{\sigma_{yf}}$$

$$\Longrightarrow \qquad q \leq \frac{C_4^{\,2}(g_3+\nu_f g_4)}{g_8^{\,2}} \sigma_{ys}^{\,2} \frac{2\rho_f}{\rho_s \sigma_{yf}} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-3)/2A}$$

(b) Face wrinkling-core shearing fail simultaneously

$$q_{cs} = \frac{C_4 \sigma_{ys} c(\rho_c/\rho_s)^B}{g_8 a}$$

$$\Longrightarrow \quad \rho_c/\rho_s = \left(\frac{qag_8}{C_4\sigma_{ys}c}\right)^{1/B}$$

$$q_{fw} = \frac{\alpha ct(\rho_c/\rho_s)^{2A/3}}{a^2(g_3+\nu_f g_4)}$$

$$\Longrightarrow \quad t = \frac{qa^2(g_3+\nu_f g_4)}{\alpha c}\left(\frac{C_4\sigma_{ys}c}{qag_8}\right)^{2A/3B}$$

The weight function is

$$W = 2\rho_f abt + \rho_c abc$$

Letting $\partial W/\partial c = 0$. It is found

$$c_{opt} = \left[\frac{\rho_s(3-3B)\alpha}{2\rho_f(2A-3B)qa^2(g_3+\nu_f g_4)}\left(\frac{qag_8}{C_4\sigma_{ys}}\right)^{(2A+3)/3B}\right]^{3B/(2A-6B+3)}$$

$$(\rho_c)_{opt} = \rho_s\left(\frac{qag_8}{C_4\sigma_{ys}c_{opt}}\right)^{1/B}$$

$$t_{opt} = \frac{qa^2(g_3+\nu_f g_4)}{\alpha(\rho_c/\rho_s)_{opt}^{2A/3}c_{opt}}$$

Similarly, from the failure mode map, there is a restriction in ρ_c/ρ_s for face wrinkling-core shearing failure mode.

i.e.

$$(\rho_c/\rho_s)_{opt} = \left(\frac{qag_8}{C_4\sigma_{ys}c_{opt}}\right)^{1/B} \le \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha}\right)^{3/2A}$$

Therefore,

$$q \leq \frac{2\rho_f(2A-3B)C_4{}^2\sigma_{ys}{}^2(g_3+\nu_f g_4)}{\rho_s(3-3B)g_f{}^2\alpha} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-2A-3)/2A}$$

(c) <u>Face yielding-core shearing fail simultaneously</u>

$$q_{fy} = \frac{\sigma_{yf}ct}{a^2(g_3+\nu_f g_4)}$$

$$\Longrightarrow \quad t = \frac{qa^2(g_3+\nu_f g_4)}{\sigma_{yf}c}$$

$$q_{cs} = \frac{C_4(\rho_c/\rho_s)^B\sigma_{ys}c}{g_8 a}$$

$$\Longrightarrow \quad \rho_c = \rho_s \left(\frac{qag_8}{C_4\sigma_{ys}c} \right)^{1/B}$$

The weight function is

$$W = 2\rho_f abt + \rho_c abc$$

Letting $\partial W/\partial c = 0$. We can find

$$c_{opt} = \left[\frac{2\rho_f Bqa^2(g_3+\nu_f g_4)}{\rho_s(B-1)\sigma_{yf}} \left(\frac{C_4\sigma_{ys}}{qag_8} \right)^{1/B} \right]^{B/(2B-1)}$$

$$t_{opt} = \frac{qa^2(g_3+\nu_f g_4)}{\sigma_{yf}c_{opt}}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{qag_8}{C_4\sigma_{ys}c_{opt}} \right)^{1/B}$$

In order for face yielding and core shearing to occur at the

same time there is a limitation in ρ_c/ρ_s according to the failure mode map. That is

$$(\rho_c/\rho_s)_{opt} = \left(\frac{qag_8}{C_4\sigma_{ys}c_{opt}} \right)^{1/B} \geq \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Therefore,

$$q \geq \frac{2\rho_f BC_4{}^2\sigma_{ys}{}^2(g_3+\nu_f g_4)}{\rho_s(B-1)\sigma_{yf}g_8{}^2} \left(\frac{\sigma_{yf}}{\alpha} \right)^{(6B-3)/2A}$$

(d) <u>Face yielding-face wrinkling -core shearing fail simultaneously</u>

$$q_{fy} = \frac{\sigma_{yf}ct}{a^2(g_3+\nu_f g_4)}$$

$$q_{fw} = \frac{\alpha ct(\rho_c/\rho_s)^{2A/3}}{a^2(g_3+\nu_f g_4)}$$

$$q_{cs} = \frac{C_4(\rho_c/\rho_s)^B\sigma_{ys}c}{ag_8}$$

The three equations in three unknowns give :

$$c_{opt} = \frac{qag_8}{C_4\sigma_{ys}} \left(\frac{\sigma_{yf}}{\alpha} \right)^{-3B/2A} = \text{constant}$$

$$t_{opt} = \frac{qa^2(g_3+\nu_f g_4)}{\sigma_{yf}\, c_{opt}} = \text{constant}$$

$$(\rho_c)_{opt} = \rho_s \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} = \text{constant}$$

In running this program, the q requirement is checked first. The optimal design is evaluated for each case for which the condition is met. Among the above possible failure modes, the one with the minimum weight is selected as the overall optimum design.

V. Minimum Weight Design for Both Stiffness and Strength

In practice, the minimum weight design should take both stiffness and strength requirements into account. In this program, there are three kinds of failure mode considered for sandwich plates.

(a) Stiffness and face yielding failure

$$q_{fy} = \frac{\sigma_{yf} c t}{a^2 (g_3 + \nu_f g_4)}$$

$$\Longrightarrow \quad c = \frac{q a^2 (g_3 + \nu_f g_4)}{\sigma_{yf} \; t}$$

$$\Delta = \frac{q a^4}{16D} g_1 + \frac{q a^2}{4S} g_2$$

$$\Longrightarrow \quad \rho_c = \left(\frac{a^2 g_2}{4 C_s E_s c} \left[\frac{\Delta}{q} - \frac{a^4 (1-\nu_f^2) g_1}{8 E_f t c^2} \right]^{-1} \right)^{1/G} \rho_s$$

Therefore, the weight function becomes

$$W = 2\rho_f abt + \frac{\rho_s abqa^2(g_3+\nu_f g_4)}{\sigma_{yf}} \left[\frac{8q^2a^4 g_2 E_f (g_3+\nu_f g_4)}{4C_g E_s \sigma_{yf}} \right]^{1/G}$$

$$\left[\frac{8\Delta E_f q^2 a^4 (g_3+\nu_f g_4)^2 t^{G-1} - a^4 q(1-\nu_f^2) g_1 \sigma_{yf}^2 t^G}{\sigma_{yf}^2} \right]^{-1/G}$$

Since the weight of the sandwich plate is a real number, the value in the bracket should be larger than zero. From this observation it is concluded that

$$0 < t < \frac{8\Delta E_f q(g_3+\nu_f g_4)^2}{(1-\nu_f^2) g_1 \sigma_{yf}^2}$$

There is a constraint for face yielding failure.

$$(\rho_c/\rho_s)_{opt} \geq \rho_c/\rho_s = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Within the range, a minimum weight can be found by incrementally increasing t. The corresponding face and core thicknesses and foam density are the optimal design values.

<u>(b) Stiffness and face wrinkling failure</u>

$$q_{fw} = \frac{\alpha ct(\rho_c/\rho_s)^{2A/3}}{a^2(g_3+\nu_f g_4)}$$

$$\Longrightarrow \quad t = \frac{qa^2(g_3+\nu_f g_4)}{\alpha c} (\rho_c/\rho_s)^{-2A/3}$$

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

$$\Longrightarrow \quad c = \frac{a^2 \alpha g_1 (1-\nu_f^2)}{8\Delta E_f (g_3+\nu_f g_4)} (\rho_c/\rho_s)^{2A/3} + \frac{qa^2 g_2}{4C_g E_s \Delta} (\rho_c/\rho_s)^{-G}$$

The weight function is

$$W = 2\rho_f abt + \rho_c abc$$

From the failure mode map, it is known that there is a limitation in ρ_c/ρ_s for occurrence of face wrinkling.

$$0 < \rho_c/\rho_s \le \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A}$$

Also, there is another constraint for face wrinkling failure.

$$\frac{t}{a} \le \frac{C_4 \sigma_{ys} (g_3+\nu_f g_4)(\rho_c/\rho_s)^{B-2A/3}}{\alpha g_8}$$

The value which corresponds to the minimum weight can be found using the same argument as that for the constraints of stiffness and the face yielding failure mode.

(c) Stiffness, face yielding and face wrinkling

$$q_{fy} = \frac{\sigma_{yf} ct}{a^2 (g_3+\nu_f g_4)}$$

$$q_{fw} = \frac{\alpha ct (\rho_c/\rho_s)^{2A/3}}{a^2 (g_3+\nu_f g_4)}$$

$$\Delta = \frac{qa^4}{16D} g_1 + \frac{qa^2}{4S} g_2$$

The three constraints in three variables can be solved for :

$$(\rho_c/\rho_s)_{opt} = \left(\frac{\sigma_{yf}}{\alpha} \right)^{3/2A} = \text{constant}$$

$$c_{opt} = \frac{a^2 \sigma_{yf} g_1 (1-\nu_f^{\;2})}{8\Delta E_f (g_3+\nu_f g_4)} + \frac{qa^2 g_2}{4C_s E_s \Delta} \left(\frac{\sigma_{yf}}{\alpha} \right)^{-3G/2A} = \text{constant}$$

$$t_{opt} = \frac{qa^2 (g_3+\nu_f g_4)}{\sigma_{yf}\, c_{opt}} = \text{constant}$$

In running this program, the three failure modes considered above will be compared with each other to determine the overall minimum weight design.

It is noted that the stiffness-core shearing failure mode is not included in this program because it ends up with an impractically large core thickness.

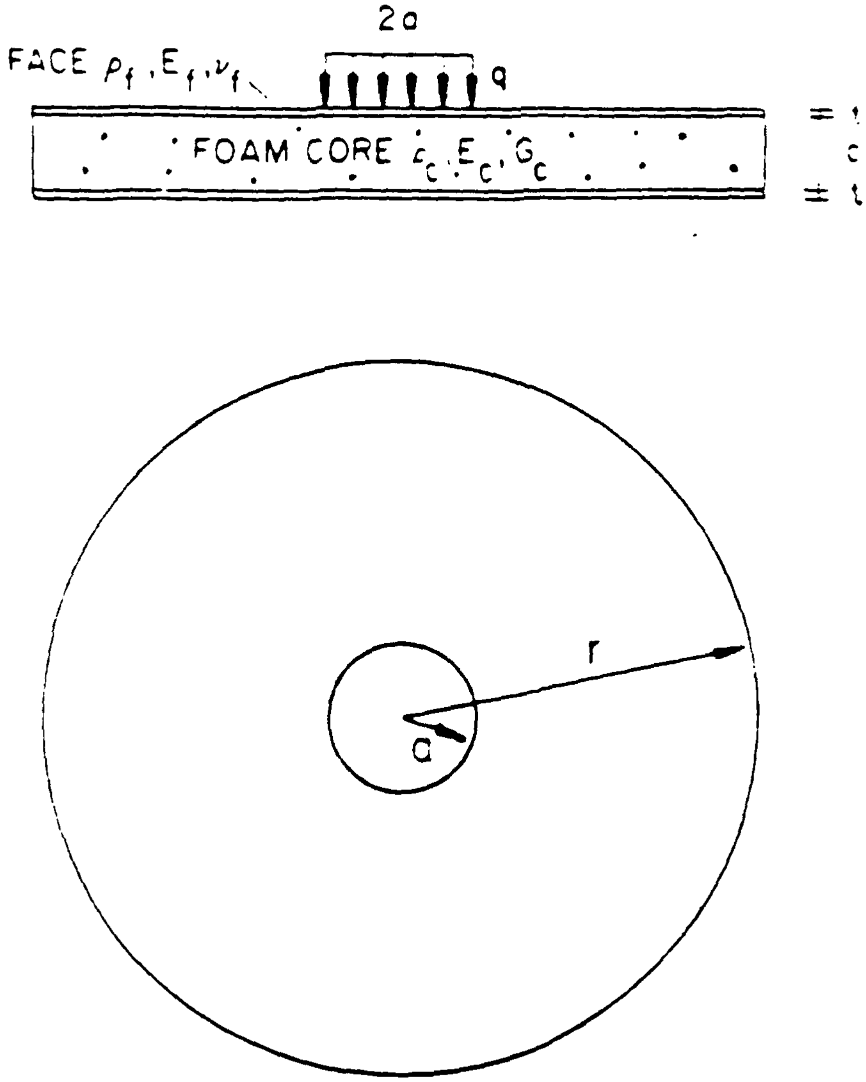


Figure 4. The geometry of a circular sandwich plate.

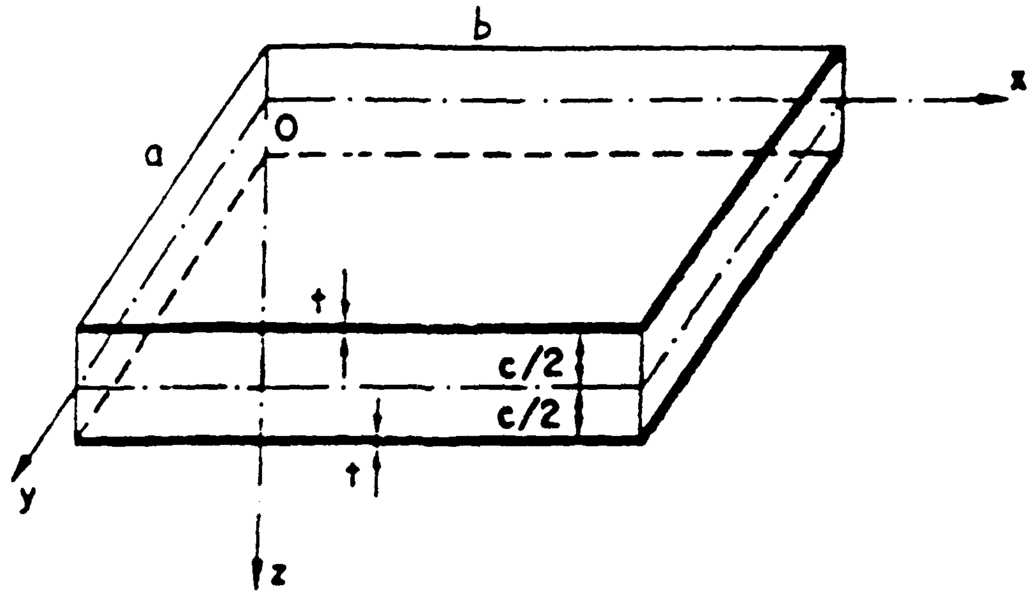


Figure 5. The geometry of a rectangular sandwich plate.

Appendix

Simply supported circular sandwich plate :

$$g_1 = \frac{3+\nu_f}{1+\nu_f}(r/a)^2 + \ln(a/r) - \frac{7+3\nu_f}{4(1+\nu_f)}$$

$$g_2 = 1 + 2\ln(r/a)$$

$$g_3 = 1/2 + \frac{1}{2}\ln(r/a) - \frac{a^2}{8r^2}$$

$$g_4 = \frac{1}{2}\ln(r/a) + \frac{a^2}{8r^2}$$

$$g_5 = \frac{1}{2} + \frac{1}{2}\ln(r/a) - \frac{a^2}{8r^2}$$

$$g_6 = \frac{1}{2}\ln(r/a) + \frac{a^2}{8r^2}$$

$$g_7 = 0$$

$$g_8 = 1/2$$

$$g_9 = 1/2$$

Clamped circular sandwich plate :

(1) $a > 0.588r$

$$g_1 = (r/a)^2 - \ln(r/a) - \frac{3}{4}$$

$$g_2 = 1 + 2\ln(r/a)$$

$$g_3 = g_6 = \frac{1}{2} - \frac{a^2}{4r^2}$$

$$g_4 = g_5 = 0$$

$$g_7 = 0$$

$$g_8 = g_9 = 1/2$$

(2) $a < 0.588r$

$$g_1 = (r/a)^2 - \ln(r/a) - \frac{3}{4}$$

$$g_2 = 1 + 2\ln(r/a)$$

$$g_3 = g_4 = g_5 = g_6 = \frac{1}{2}\ln(r/a) + \frac{a^2}{8r^2}$$

$$g_7 = 0$$

$$g_8 = g_9 = 1/2$$

Simply supported rectangular sandwich plate :

$$g_1 = \frac{(16)^2}{\pi^6} \sum\sum \frac{(-1)^{(m-1)/2} (-1)^{(n-1)/2}}{mn\Omega^2}$$

$$g_2 = \frac{64}{\pi^4} \sum\sum \frac{(-1)^{(m-1)/2}(-1)^{(n-1)/2}}{mn\Omega}$$

$$g_3 = g_6 = \frac{16}{\pi^4} \sum\sum \frac{(-1)^{(m-1)/2}(-1)^{(n-1)/2}}{\Omega^2} \frac{ma^2}{nb^2}$$

$$g_4 = g_5 = \frac{16}{\pi^4} \sum\sum \frac{(-1)^{(m-1)/2}(-1)^{(n-1)/2}}{\Omega^2} \frac{n}{m}$$

$$g_7 = \frac{16}{\pi^4} \sum\sum \frac{a}{b\Omega^2}$$

$$g_8 = \frac{16}{\pi^3} \sum\sum \frac{(-1)^{(n-1)/2}}{n\Omega} \frac{a}{b}$$

$$g_9 = \frac{16}{\pi^3} \sum\sum \frac{(-1)^{(m-1)/2}}{m\Omega}$$

where $\Omega = \dfrac{m^2 a^2}{b^2} + n^2$

$m, n = 1, 3, 5, 7, \text{----------} ,23$

```
      PROGRAM SWP
*****************************************************************
*****************************************************************
***                                                           ***
***      THIS PROGRAM WAS CREATED BY JONG-SHIN HUANG          ***
***      IN AUGUST 1988 FOR OPTIMUM DESIGN METHODS OF         ***
***      STRUCTURAL SANDWICH PANELS                           ***
***                                                           ***
*****************************************************************
*****************************************************************
      INTEGER TY,CONFI,FAIL
      REAL C5(10),C6(10),EF,EC,GC,WS,SS,UDL,MCL,LCL,M,SD,D,YF,YS,C3,A,G8
      REAL STEP,Z,SIGMAC,TAUC,SIGMAF,TAUF,AREA,DEFL,ES,ROS,CG,ROF,G,B,G9
      REAL STIFF,WEIGHT,THETA,AL,RCP,NUF,G1,G2,AA,BB,P,C4,Q,PP,TL,CRIT
      REAL OMEGA,S,C1(10),C2(10),RCS,DELTA,STR1,STR2,STR3,G3,G4,G5,G6,G7
      DOUBLE PRECISION TF,TC,ROC,COEFF,STREN,AFA
      OPEN(UNIT=7,FILE='SWP.OUT',STATUS='NEW')
      WRITE(*,1)
    1 FORMAT(T2,'WHAT KIND OF PROBLEM DO YOU WANT TO RUN ?',/,T10,
     $' 1 - ANALYSIS OF SANDWICH BEAMS',/,T10,
     $' 2 - MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEAMS',/,
     $T10,' 3 - MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS',
     $/,T10,' 4 - MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SA
     $NDWICH BEAMS',
     $/,T10,' 5 - ANALYSIS OF SANDWICH PLATES',/,T10,
     $' 6 - MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH PLATES',/,
     $T10,' 7 - MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH PLATES',
     $/,T10,' 8 - MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SA
     $NDWICH PLATES')
      READ(*,*)TY
      IF (TY.EQ.1) WRITE(7,51)
      IF (TY.EQ.2) WRITE(7,52)
      IF (TY.EQ.3) WRITE(7,53)
      IF (TY.EQ.4) WRITE(7,54)
      IF (TY.EQ.5) WRITE(7,55)
      IF (TY.EQ.6) WRITE(7,56)
      IF (TY.EQ.7) WRITE(7,57)
      IF (TY.EQ.8) WRITE(7,58)
   51 FORMAT(//,T10,'ANALYSIS OF SANDWICH BEAMS',/)
   52 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEA
     $MS',/)
   53 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAM
     $S',/)
   54 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN
     $ SANDWICH BEAMS',/)
   55 FORMAT(//,T10,'ANALYSIS OF SANDWICH PLATES',/)
   56 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH PLA
     $TES',/)
   57 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH PLAT
     $ES',/)
   58 FORMAT(//,T10,'MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN
     $ SANDWICH PLATES',/)

*********************************************
***      INPUT THE MATERIAL PROPERTIES    ***
*********************************************
      WRITE(*,*)'INPUT THE ELASTIC MODULUS OF FACE MATERIAL ( ksi )'
      READ(*,*)EF
      WRITE(*,*)'INPUT THE YIELD STRENGTH OF FACE MATERIAL ( ksi )'
      READ(*,*)YF
```

```
      WRITE(*,*)'INPUT THE MASS DENSITY OF FACE MATERIAL ( pcf )'
      READ(*,*)ROF
      WRITE(*,*)'INPUT THE ELASTIC MODULUS OF SOLID FOAM ( ksi )'
      READ(*,*)ES
      WRITE(*,*)'INPUT THE YIELD STRENGTH OF SOLID FOAM ( ksi )'
      READ(*,*)YS
      WRITE(*,*)'INPUT THE MASS DENSITY OF SOLID FOAM ( pcf )'
      READ(*,*)ROS
      WRITE(*,*)'INPUT THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS
     $OF FOAM CORE'
      READ(*,*)C3
      WRITE(*,*)'INPUT THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM CO
     $RE'
      READ(*,*)A
      WRITE(*,*)'INPUT THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF
     $ FOAM CORE'
      READ(*,*)CG
      WRITE(*,*)'INPUT THE POWER CONSTANT FOR SHEAR MODULUS OF FOAM CORE
     $'
      READ(*,*)G
      WRITE(*,*)'INPUT THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH O
     $F FOAM CORE'
      READ(*,*)C4
      WRITE(*,*)'INPUT THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM COR
     $E'
      READ(*,*)B
      WRITE(7,75)EF,YF,ROF,ES,YS,ROS,C3,A,CG,G,C4,B
   75 FORMAT(T10,'THE ELASTIC MODULUS OF FACE MATERIAL =',T50,F12.3,T65,
     $'( ksi )',//,T10,'THE YIELD STRENGTH OF FACE MATERIAL =',T50,F12.3
     $,T65,'( ksi )',//,T10,'THE MASS DENSITY OF FACE MATERIAL =',T50,F1
     $2.3,T65,'( pcf )',//,T10,'THE ELASTIC MODULUS OF SOLID FOAM =',T50
     $,F12.3,T65,'( ksi )',//,T10,'THE YIELD STRENGTH OF SOLID FOAM =',
     $T50,F12.3,T65,'( ksi )',//,T10,'THE MASS DENSITY OF SOLID FOAM =',
     $T50,F12.3,T65,'( pcf )',//,T10,'THE PROPORTIONALITY CONSTANT',/,
     $T10,'FOR ELASTIC MODULUS OF FOAM CORE =',T50,F12.3,//,T10,
     $'THE POWER CONSTANT',/,T10,'FOR ELASTIC MODULUS OF FOAM CORE =',
     $T50,F12.3,//,T10,'THE PROPORTIONALITY CONSTANT',/,T10,
     $'FOR SHEAR MODULUS OF FOAM CORE =',T50,F12.3,//,T10,
     $'THE POWER CONSTANT',/,T10,'FOR SEAR MODULUS OF FOAM CORE =',
     $T50,F12.3,//,T10,'THE PROPORTIONALITY CONSTANT',/,T10,
     $'FOR SHEAR STRENGTH OF FOAM CORE =',T50,F12.3,//,T10,
     $'THE POWER CONSTANT',/,T10,'FOR SHEAR STRENGTH OF FOAM CORE =',
     $T50,F12.3,/)
      AFA=0.57*C3**(2./3.)*EF**(1./3.)*ES**(2./3.)
      GO TO (100,100,100,100,300,300,300,300),TY

*********************************************************
*********************************************************
***      A. ANALYSIS AND DESIGN OF SANDWICH BEAMS      ***
*********************************************************
*********************************************************

*************************************************************
**      INPUT THE CONFIGURATION AND LOADING GEOMETRY      ***
*************************************************************
  100 DATA C1(1),C1(2),C1(3),C1(4),C1(5),C1(6)/4,1,8,8,2,12/
      DATA C2(1),C2(2),C2(3),C2(4),C2(5),C2(6)/2,1,2,2,1,2/
      DATA C5(1),C5(2),C5(3),C5(4),C5(5),C5(6)/48,3,192,76.8,8,384/
      DATA C6(1),C6(2),C6(3),C6(4),C6(5),C6(6)/4,1,4,8,2,8/
      WRITE(*,101)
```

```
101 FORMAT(T2,' WHAT IS THE CONFIGURATION AND LOADING GEOMETRY ?',/,
   $T15,' 1 - SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD',/,
   $T15,' 2 - CANTILEVER UNDER CONCENTRATED LOAD',/,
   $T15,' 3 - FIXED ENDS UNDER CONCENTRATED LOAD',/,
   $T15,' 4 - SIMPLY-SUPPORTED UNDER UNIFORM DISTRIBUTED LOAD',/,
   $T15,' 5 - CANTILEVER UNDER UNIFORM DISTRIBUTED LOAD',/,
   $T15,' 6 - FIXED ENDS UNDER UNIFORM DISTRIBUTED LOAD')
    READ(*,*)CONFI
    IF (CONFI.EQ.1) WRITE(7,111)
    IF (CONFI.EQ.2) WRITE(7,112)
    IF (CONFI.EQ.3) WRITE(7,113)
    IF (CONFI.EQ.4) WRITE(7,114)
    IF (CONFI.EQ.5) WRITE(7,115)
    IF (CONFL.EQ.6) WRITE(7,116)
111 FORMAT(T10,'SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD',/)
112 FORMAT(T10,'CANTILEVER UNDER CONCENTRATED LOAD',/)
113 FORMAT(T10,'FIXED ENDS UNDER CONCENTRATED LOAD',/)
114 FORMAT(T10,'SIMPLY-SUPPORTED UNDER UNIFORM DISTRIBUTED LOAD',/)
115 FORMAT(T10,'CANTILEVER UNDER UNIFORM DISTRIBUTED LOAD',/)
116 FORMAT(T10,'FIXED ENDS UNDER UNIFORM DISTRIBUTED LOAD',/)
    WRITE(*,*)'INPUT THE WIDTH OF THE SANDWICH BEAM ( in. )'
    READ(*,*)WS
    WRITE(*,*)'INPUT THE SPAN OF THE SANDWICH BEAM ( in. )'
    READ(*,*)SS
    WRITE(7,117)WS,SS
117 FORMAT(T10,'THE WIDTH OF THE SANDWICH BEAM -',T50,F10.3,T65,'( in.
   $ )',//,T10,'THE SPAN OF THE SANDWICH BEAM  -',T50,F10.3,T65,'( in.
   $ )',/)
    IF (TY.EQ.2) GO TO 200
    IF (TY.EQ.3) GO TO 250
    IF (TY.EQ.4) GO TO 270

**********************************************
**********************************************
***      1. ANALYSIS OF SANDWICH BEAMS     ***
**********************************************
**********************************************
    WRITE(*,*)'INPUT THE MASS DENSITY OF FOAM CORE ( pcf )'
    READ(*,*)ROC
    WRITE(*,*)'INPUT THE THICKNESS OF FACE MATERIAL ( in. )'
    READ(*,*)TF
    WRITE(*,*)'INPUT THE THICKNESS OF FOAM CORE ( in. )'
    READ(*,*)TC
    WRITE(7,125)ROC,TF,TC
    EC=C3*(ROC/ROS)**A*ES
    GC=CG*(ROC/ROS)**G*ES
    IF (CONFI.GE.4) THEN
         WRITE(*,*)'INPUT THE MAGNITUDE OF UNIFORM LOAD ( kips/in )'
         READ(*,*)UDL
         WRITE(7,126)UDL
    ELSE IF (CONFI.LT.4) THEN
         WRITE(*,*)'INPUT THE MAGNITUDE OF THE CONCENTRATED LOAD ( kip
   $s )'
         READ(*,*)MCL
         WRITE(*,*)'INPUT THE LOCATION OF THE CONCENTRATED LOAD ( in.
   $)'
         WRITE(*,*)'*** THE LOCATION IS MEASURED FROM THE FREE END FOR
   $CANTILEVER BEAM ***'
         READ(*,*)LCL
         WRITE(7,127)MCL,LCL
```

```
          AL=(SS-LCL)/SS
          IF (AL.LT.0.01) WRITE(*,*)'** CHECK THE LOCATION OF LOAD **'
      END IF
  125 FORMAT(T10,'THE MASS DENSITY OF CORE MATERIAL =',T50,F12.3,T65,
     $'( pcf )',//,T10,'THE THICKNESS OF FACE MATERIAL =',T50,F12.3,
     $T65,'( in. )',//,T10,'THE THICKNESS OF FOAM CORE =',T50,F12.3,
     $T65,'( in. )',/)
  126 FORMAT(T10,'THE MAGNITUDE OF UNIFORM      LOAD   =',T50,F12.3,
     $T65,'( kips/in. )',/)
  127 FORMAT(T10,'THE MAGNITUDE OF CONCENTRATED LOAD   =',T50,F12.3,
     $T65,'( kips )',//,
     $T10,'THE LOCATION  OF CONCENTRATED LOAD   =',T50,F12.3,
     $T65,'( in. )',/)

*****************************************************************
***      CALCULATE THE CRITICAL BENDING AND SHEAR STRESSES      ***
*****************************************************************
      IF (CONFI.EQ.1) THEN
          IF (AL.LT.0.5) AL=1-AL
          C1(1)=1./(AL*(1-AL))
          C2(1)=1./AL
          C5(1)=27./(AL*(1-AL)*(2-AL)*(3*AL*(2-AL))**0.5)
          C6(1)=1./(AL*(1-AL))
      ELSE IF (CONFI.EQ.2) THEN
          C1(2)=1./AL
          C2(2)=1.
          C5(2)=6./(3*AL*AL-AL**3)
          C6(2)=1./AL
      ELSE IF (CONFI.EQ.3) THEN
          IF (AL.GT.0.5) AL=1-AL
          C1(3)=1./(AL*(1-AL)**2)
          C2(3)=1./((1-AL)**2*(1+2*AL))
          C5(3)=3*(3-2*AL)**2/(2*AL**2*(1-AL)**3)
          C6(3)=1./(AL*(1-AL)**2*(1+2*AL))
      END IF
      SD=TF+TC
      D=EF*WS*TF**3/6.+EF*WS*TF*SD**2/2.+EC*WS*TC**3/12.
      IF (CONFI.GE.4) THEN
          M=UDL*SS**2/C1(CONFI)
          Q=UDL*SS/C2(CONFI)
      ELSE IF (CONFI.LT.4) THEN
          M=MCL*SS/C1(CONFI)
          Q=MCL/C2(CONFI)
      END IF
      WRITE(*,130)
      WRITE(7,130)
  130 FORMAT(/,T5,'THE CRITICAL BENDING AND SHEAR STRESSES :',//,T10,
     $'Z ( in )',T25,'SIGMAC ( ksi )',T40,'TAUC ( ksi )',/)
      STEP=TC/40.
      Z=0.0
      DO 140 I=1,21
      SIGMAC=M*Z*EC/D
      TAUC=(EF*TF*SD/2.+EC*(TC**2/4.-Z*Z)/2.)*Q/D
      WRITE(*,135)Z,SIGMAC,TAUC
      WRITE(7,135)Z,SIGMAC,TAUC
  135 FORMAT(T5,F7.3,T20,F12.6,T35,F12.6)
      Z=Z+STEP
  140 CONTINUE
      WRITE(*,145)
      WRITE(7,145)
```

```
  145 FORMAT(/,T10,'Z ( in )',T25,'SIGMAF ( ksi )',T40,'TAUF ( ksi )',/)
      STEP=TF/20.
      Z=TC/2.
      DO 150 I=1,21
      SIGMAF=M*Z*EF/D
      TAUF=Q*EF*(((TC/2.+TF)**2-Z*Z)/2.)/D
      WRITE(*,135)Z,SIGMAF,TAUF
      WRITE(7,135)Z,SIGMAF,TAUF
      Z=Z+STEP
  150 CONTINUE

************************************************
***      CALCULATE THE MAXIMUM DEFLECTION     ***
************************************************
      AREA=WS*SD**2/TC
      IF (CONFI.GE.4) THEN
           DEFL=UDL*SS**4/(C5(CONFI)*D)+UDL*SS**2/(AREA*GC*C6(CONFI))
      ELSE IF (CONFI.LT.4) THEN
           DEFL=MCL*SS**3/(C5(CONFI)*D)+MCL*SS/(C6(CONFI)*AREA*GC)
      END IF
      WRITE(*,160)DEFL
      WRITE(7,160)DEFL
  160 FORMAT(/,T10,'THE MAXIMUM DEFLECTION =',T35,F12.6,T50,'( in. )')

************************************************
***      JUDGE THE STRENGTH FAILURE MODE      ***
************************************************
      PFY=C1(CONFI)*YF*WS*TC*TF/SS
      PFW=AFA*C1(CONFI)*(ROC/ROS)**(2.*A/3.)*WS*TC*TF/SS
      COEFF=(C3*(ROC/ROS)**A*ES*SS/(2.*C1(CONFI)*TF*EF))**2.
      COEFF=COEFF+(1./C2(CONFI))**2
      PCS=C4*(ROC/ROS)**B*YS*WS*TC*(1./COEFF)**0.5
      FAIL=3
      IF(PFY.LT.PFW) THEN
           IF (PFY.LT.PCS) FAIL=1
      ELSE IF (PFW.LE.PFY) THEN
           IF (PFW.LT.PCS) FAIL=2
      END IF
      IF (CONFI.GE.4) PP=UDL*SS
      IF (CONFI.LT.4) PP=MCL
      IF (FAIL.EQ.1) THEN
           WRITE(*,163)
           WRITE(7,163)
           IF ((PFY-PP).GT.0) THEN
                WRITE(*,161)
                WRITE(7,161)
           ELSE IF ((PFY-PP).LE.0) THEN
                WRITE(*,162)
                WRITE(7,162)
           END IF
      ELSE IF (FAIL.EQ.2) THEN
           WRITE(*,164)
           WRITE(7,164)
           IF ((PFW-PP).GT.0) THEN
                WRITE(*,161)
                WRITE(7,161)
           ELSE IF ((PFW-PP).LE.0) THEN
                WRITE(*,162)
                WRITE(7,162)
           END IF
```

```
      ELSE IF (FAIL.EQ.3) THEN
          WRITE(*,165)
          WRITE(7,165)
          IF ((PCS-PP).GT.0) THEN
               WRITE(*,161)
               WRITE(7,161)
          ELSE IF ((PCS-PP).LE.0) THEN
               WRITE(*,162)
               WRITE(7,162)
          END IF
      END IF
      GO TO 1000
  161 FORMAT(T10,'THE SANDWICH BEAM UNDER LOADING IS SAFE',/)
  162 FORMAT(T10,'THE SANDWICH BEAM UNDER LOADING IS NOT SAFE',/)
  163 FORMAT(/,T10,'THE FAILURE MODE IS FACE YIELDING',/)
  164 FORMAT(/,T10,'THE FAILURE MODE IS FACE WRINKLING',/)
  165 FORMAT(/,T10,'THE FAILURE MODE IS CORE SHEAR YIELDING',/)

*************************************************************************
*************************************************************************
***      2. MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEAMS     ***
*************************************************************************
*************************************************************************

****************************************************
***      INPUT THE REQUIRED DESIGN STIFFNESS     ***
****************************************************
  200 WRITE(*,*)'INPUT THE REQUIRED DESIGN STIFFNESS ( kips/in )'
      READ(*,*)STIFF
      WRITE(7,201)STIFF
  201 FORMAT(T10,'THE REQUIRED DESIGN STIFFNESS =',T50,
     $F12.5,T65,'( kips/in )',/)

****************************************************
***      CALCULATE THE OPTIMAL DESIGN VALUES     ***
****************************************************
      COEFF=4*(G*(4./(G-1))**(1./G)/(G-1))*((2+2*G)/(G-1))**(1-1./G)
      COEFF=COEFF*(SS*C5(CONFI)*EF/(CG*C6(CONFI)*ES))**(-1./G)
      COEFF=COEFF*(STIFF/(C5(CONFI)*WS*EF))**(1-1./G)
      TC=(COEFF*ROF*SS**3/ROS)**(G/(3*G-1))
      TF=2*(1+G)*STIFF*SS**3/((G-1)*C5(CONFI)*EF*WS*TC**2)
      COEFF=SS*C5(CONFI)*STIFF*EF*TC*TF/(CG*C6(CONFI)*ES)
      ROC=(COEFF/(C5(CONFI)*EF*WS*TF*TC**2-2*STIFF*SS**3))**(1./G)*ROS
      WEIGHT=(2.*ROF*WS*TF*SS+ROC*WS*TC*SS)/1728000.
      SD=TF+TC
      COEFF=(CG*(ROC/ROS)**G*ES*TC*(1+3*(SD/TF)**2)/(2*EF*TF))**0.5
      THETA=COEFF*SS/TC
      WRITE(*,215)TC,TF,ROC,WEIGHT,THETA
      WRITE(7,215)TC,TF,ROC,WEIGHT,THETA
  215 FORMAT(//,T10,'THE OPTIMAL DESIGN VALUES :',//
     $,T15,'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',//,
     $T15,'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',//,T15,
     $'THE MINIMUM WEIGHT OF SANDWICH BEAM =',T55,F12.4,T70,'kips',//,
     $T15,'THETA OF THE SHEAR LAG CRITERION =',T55,F12.4)
      GO TO 1000

*************************************************************************
*************************************************************************
**       3. MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS      ***
```

```
************************************************************************
************************************************************************

*************************************************
***.    INPUT THE REQUIRED DESIGN STRENGTH     ***
*************************************************
  250 WRITE(*,*)'INPUT THE REQUIRED DESIGN STRENGTH PER UNIT WIDTH AND L
     $ENGTH ( psi )'
      READ(*,*)STREN
      WRITE(7,251)STREN
      STREN=STREN/1000.
  251 FORMAT(T10,'THE REQUIRED DESIGN STRENGTH ',/,T10,
     $'PER UNIT WIDTH AND LENGTH =',T50,F12.4,T65,'psi',/)

**************************************************
***     CALCULATE THE OPTIMAL DESIGN VALUES     ***
**************************************************

*******   FY/FW/CS FAILURE DESIGN ******
      TC=STREN*SS*(YF/AFA)**(-1.5*B/A)/(YS*C4*C2(CONFI))
      TF=STREN*SS**2./(C1(CONFI)*YF*TC)
      ROC=(YF/AFA)**(1.5/A)*ROS
      WEIGHT=(2.*ROF*WS*TF*SS+ROC*WS*TC*SS)/1728000.
      FAIL=4
      COEFF=(YF/AFA)**((6*B-3)/(2.*A))*2*ROF*YS**2*C4**2*C2(CONFI)**2
      STR1=COEFF/(C1(CONFI)*ROS*YF)
      COEFF=(YF/AFA)**((6*B-2*A-3)/(2.*A))*(C2(CONFI)*C4*YS)**2*ROF*2
      STR2=COEFF*(2*A-3*B)/(ROS*(3.-3.*B)*C1(CONFI)*AFA)
      COEFF=(YF/AFA)**((6*B-3)/(2.*A))*(C2(CONFI)*C4*YS)**2*B*2*ROF
      STR3=COEFF/(ROS*(B-1)*C1(CONFI)*YF)
******   FW/FY FAILURE DESIGN   ******
      IF (STREN.LE.STR1) THEN
           COEFF=2*ROF*STREN*SS**2*AFA**(1.5/A)/(C1(CONFI)*ROS)
           TC1=(COEFF/(YF**(1+(1.5/A))))**0.5
           TF1=STREN*SS**2/(C1(CONFI)*YF*TC1)
           ROC1=(YF/AFA)**(1.5/A)*ROS
           W1=(2*TF1*WS*SS*ROF+TC1*WS*SS*ROC1)/1728000.
           IF (W1.LT.WEIGHT) THEN
                TF=TF1
                TC=TC1
                ROC=ROC1
                WEIGHT=W1
                FAIL=1
           END IF
      END IF
*****   FW/CS FAILURE DESIGN   ******
      IF (STREN.LE.STR2) THEN
           COEFF=(STREN*SS/(C2(CONFI)*C4*YS))**((2*A+3)/(3.*B))*AFA
           COEFF=COEFF*C1(CONFI)*ROS*(3-3*B)/(2.*ROF*(2*A-3*B))
           TC1=(COEFF/(STREN*SS**2))**(3*B/(2.*A-6.*B+3.))
           ROC1=(STREN*SS/(C2(CONFI)*C4*YS*TC1))**(1./B)*ROS
           TF1=STREN*SS**2/(C1(CONFI)*AFA*(ROC1/ROS)**(2*A/3.)*TC1)
           W1=(2*TF1*WS*SS*ROF+TC1*WS*SS*ROC1)/1728000.
           IF (W1.LT.WEIGHT) THEN
                TF=TF1
                TC=TC1
                ROC=ROC1
                WEIGHT=W1
                FAIL=2
           END IF
```

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```
      END IF
******   FY/CS FAILURE DESIGN   ******
      IF (STREN.GE.STR3) THEN
         COEFF=2*B*ROF*(STREN*SS)**((B-1)/B)*SS/(C1(CONFI)*YF)
         COEFF=(C2(CONFI)*C4*YS)**(1./B)*COEFF/(ROS*(B-1))
         TC1=COEFF**(B/(2.*B-1.))
         TF1=STREN*SS**2/(C1(CONFI)*YF*TC1)
         ROC1=(STREN*SS/(C2(CONFI)*C4*YS*TC1))**(1./B)*ROS
         W1=(2*TF1*WS*SS*ROF+TC1*WS*SS*ROC1)/1728000.
         IF (W1.LT.WEIGHT) THEN
            TF=TF1
            TC=TC1
            ROC=ROC1
            WEIGHT=W1
            FAIL=3
         END IF
      END IF
      WRITE(*,260)TC,TF,ROC,WEIGHT
      WRITE(7,260)TC,TF,ROC,WEIGHT
      IF (FAIL.EQ.1) WRITE(7,261)
      IF (FAIL.EQ.2) WRITE(7,262)
      IF (FAIL.EQ.3) WRITE(7,263)
      IF (FAIL.EQ.4) WRITE(7,264)
      GO TO 1000
  260 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUES :',//,T15,
     $'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',//,T15,
     $'THE MINIMUM WEIGHT OF SANDWICH BEAM =',T55,F12.4,T70,'kips',/)
  261 FORMAT(T15,'FY/FW FAILURE DESIGN',/)
  262 FORMAT(T15,'FW/CS FAILURE DESIGN',/)
  263 FORMAT(T15,'FY/CS FAILURE DESIGN',/)
  264 FORMAT(T15,'FY/FW/CS FAILURE DESIGN',/)

********************************************************
********************************************************
***      4. MINIMUM WEIGHT DESIGN FOR STIFFNESS      ***
***         AND STRENGTH IN SANDWICH BEAMS           ***
********************************************************
********************************************************

*******************************************
***      INPUT THE DESIGN PARAMETERS    ***
*******************************************
  270 WRITE(*,*)'INPUT THE REQUIRED DESIGN LOAD ( kips )'
      READ(*,*)P
      WRITE(*,*)'INPUT THE REQUIRED DESIGN DEFLECTION ( in )'
      READ(*,*)DELTA
      WRITE(7,271)P,DELTA
  271 FORMAT(T10,'THE REQUIRED DESIGN LOAD =',T50,F12.4,T65,'kips',//,
     $T10,'THE REQUIRED DESIGN DEFLECTION =',T50,F12.4,T65,'in.',/)

*****************************************************
***      CALCULATE THE OPTIMAL DESIGN VALUES      ***
*****************************************************

***      S+FY FAILURE DESIGN      ***
      RCS=(YF/AFA)**(1.5/A)*ROS
      CRIT=DELTA*C5(CONFI)*EF*P/(2*C1(CONFI)**2*YF**2*WS*SS*1000.)
      TF1=CRIT
```

```
      WEIGHT-1000000.
      FAIL-1
      WRITE(*,*)'THE PROGRAM IS RUNNING. PLEASE WAIT!'
      DO 273 I-1,999
           TC1-P*SS/(C1(CONFI)*YF*WS*TF1)
           COEFF-C5(CONFI)*EF*P*SS*TF1*TC1/(CG*C6(CONFI)*ES)
           COEFF-COEFF/(C5(CONFI)*DELTA*WS*TF1*TC1**2*EF-2*P*SS**3)
           ROC1-COEFF**(1./G)*ROS
           W1-(2*ROF*WS*SS*TF1+ROC1*WS*SS*TC1)/1728000.
           IF (ROC1.GE.RCS) THEN
                IF (W1.LE.WEIGHT) THEN
                     TC-TC1
                     TF-TF1
                     ROC-ROC1
                     WEIGHT-W1
                END IF
           END IF
           TF1-TF1+CRIT
  273 CONTINUE

***      S+FW FAILURE DESIGN      ***
      CRIT-RCS/1000.
      ROC1-CRIT
      DO 274 I-1,999
           COEFF-2*SS**2*AFA*C1(CONFI)*(ROC1/ROS)**(2*A/3.)/C5(CONFI)
           TC1-COEFF/(DELTA*EF)+P*SS/(CG*C6(CONFI)*ES*WS*DELTA*
     $          (ROC1/ROS)**G)
           TF1-P*SS*(ROC1/ROS)**(-2*A/3.)/(AFA*C1(CONFI)*WS*TC1)
           W1-(2*ROF*WS*SS*TF1+ROC1*WS*SS*TC1)/1728000.
           TL-C2(CONFI)*C4*YS*(ROC1/ROS)**(B-2*A/3.)/(AFA*C1(CONFI))
           IF ((TF1/SS).LE.TL) THEN
                IF (W1.LE.WEIGHT) THEN
                     TC-TC1
                     TF-TF1
                     ROC-ROC1
                     WEIGHT-W1
                     FAIL-2
                END IF
           END IF
           ROC1-ROC1+CRIT
  274 CONTINUE

***      S+FY+FW FAILURE DESIGN      ***
      ROC1-(YF/AFA)**(1.5/A)*ROS
      COEFF-2*SS**2*C1(CONFI)*YF/(C5(CONFI)*DELTA*EF)
      TC1-COEFF+P*SS*(YF/AFA)**(-1.5*G/A)/(CG*C6(CONFI)*ES*WS*DELTA)
      TF1-P*SS/(C1(CONFI)*YF*WS*TC1)
      W1-(2*ROF*WS*SS*TF1+ROC1*WS*SS*TC1)/1728000.
      IF (W1.LE.WEIGHT) THEN
           TC-TC1
           TF-TF1
           ROC-ROC1
           WEIGHT-W1
           FAIL-3
      END IF

      WRITE(*,280)TC,TF,ROC,WEIGHT
      WRITE(7,280)TC,TF,ROC,WEIGHT
      IF (FAIL.EQ.1) WRITE(7,281)
      IF (FAIL.EQ.2) WRITE(7,282)
```

```
      IF (FAIL.EQ.3) WRITE(7,283)
      GO TO 1000
  280 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUE :',//,T15,
     $'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',//,T15,
     $'THE MINIMUM WEIGHT OF SANDWICH BEAM =',T55,F12.4,T70,'kips',/)
  281 FORMAT(T15,'STIFFNESS/FY FAILURE DESIGN',/)
  282 FORMAT(T15,'STIFFNESS/FW FAILURE DESIGN',/)
  283 FORMAT(T15,'STIFFNESS/FY/FW FAILURE DESIGN',/)


**********************************************************
**********************************************************
***      B. ANALYSIS AND DESIGN OF SANDWICH PLATES     ***
**********************************************************
**********************************************************

*************************************************************
***      INPUT THE CONFIGURATION AND LOADING GEOMETRY     ***
***           AND CALCULATE G1----G9 COEFFICIENTS         ***
*************************************************************
  300 WRITE(*,301)
  301 FORMAT(T2,'WHAT IS THE CONFIGURATION AND LOADING GEOMETRY ?',/,
     $T15,'1 = CIRCULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD.',/,
     $T15,'2 = CIRCULAR PLATE, CLAMPED UNDER UNIFORM LOAD.',/,
     $T15,'3 = RECTANGULAR PLATE,SIPLY-SUPPORTED UNDER UNIFORM LOAD.')
      READ(*,*)CONFI
      IF (CONFI.EQ.1) WRITE(7,311)
      IF (CONFI.EQ.2) WRITE(7,312)
      IF (CONFI.EQ.3) WRITE(7,313)
  311 FORMAT(T10,'CIRCULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD',
     $/)
  312 FORMAT(T10,'CIRCULAR PLATE, CLAMPED UNDER UNIFORM LOAD',/)
  313 FORMAT(T10,'RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD
     $',/)
      WRITE(*,*)'INPUT THE POISSON''S RATIO OF THE FACE MATERIAL'
      READ(*,*)NUF
      WRITE(7,323)NUF
      IF (CONFI.LE.2) THEN
            WRITE(*,*)'INPUT THE RADIUS OF THE CIRCULAR PLATE ( in. )'
            READ(*,*)RCP
            WRITE(7,321)RCP
            WRITE(*,*)'INPUT THE RADIUS OF THE UNIFORM LOAD ( in. )'
            READ(*,*)AA
            WRITE(7,322)AA
  321 FORMAT(T10,'THE RADIUS OF THE CIRCULAR PLATE =',T50,F12.3,T65,
     $'( in. )',/)
  322 FORMAT(T10,'THE RADIUS OF THE UNIFORM LOAD =',T50,F12.3,T65,
     $'( in. )',/)
  323 FORMAT(T10,'THE POISSON''S RATIO OF THE FACE MATERIAL =',T50,
     $F12.3,/)
            IF (CONFI.EQ.1) THEN
                  G1=(3+NUF)*(RCP/AA)**2/(1+NUF)+LOG(AA/RCP)
     $            -(7+3*NUF)/(4*(1+NUF))
                  G3=0.5+0.5*LOG(RCP/AA)-AA**2/(8*RCP**2)
                  G4=0.5*LOG(RCP/AA)+AA**2/(8*RCP**2)
                  G5=G3
                  G6=G4
```

```
          ELSE IF (CONFI.EQ.2) THEN
               G1-(RCP/AA)**2-LOG(RCP/AA)-0.75
               IF ((AA-0.588*RCP).GE.0) THEN
                    G3-0.5-AA**2/(4*RCP**2)
                    G4-0.
                    G5-0.
                    G6-G3
               ELSE IF ((AA-0.588*RCP).LT.0) THEN
                    G3-0.5*LOG(RCP/AA)+AA**2/(8*RCP**2)
                    G4-G3
                    G5-G3
                    G6-G3
               END IF
          END IF
          G2-1+2*LOG(RCP/AA)
          G7-0.
          G8-0.5
          G9-0.5
     ELSE IF (CONFI.GE.3) THEN
          WRITE(*,*)'INPUT THE LENGTH ( X DIRECTION ) OF THE RECTANGULA
    $R PLATE ( in. )'
          READ(*,*)BB
          WRITE(7,324)BB
          WRITE(*,*)'INPUT THE WIDTH ( Y DIRECTION ) OF THE RECTANGULAR
    $PLATE ( in. )'
          READ(*,*)AA
          WRITE(7,325)AA
 324 FORMAT(T10,'THE LENGTH ( X DIRECTION ) OF',/,T15,
    $'THE RECTANGULAR PLATE =',T50,F12.3,T65,'( in. )',/)
 325 FORMAT(T10,'THE  WIDTH ( Y DIRECTION ) OF',/,T15,
    $'THE RECTANGULAR PLATE =',T50,F12.3,T65,'( in. )',/)
          DO 330 I-0,11
          M-2*I+1
              DO 330 J-0,11
              N-2*J+1
              OMEGA-(M*AA/BB)**2+N**2
              G1-G1+16**2*(-1)**I*(-1)**J/(3.14159**6*M*N*OMEGA**2)
              G2-G2+64*(-1)**I*(-1)**J/(3.14159**4*M*N*OMEGA)
              G3-G3+16*(-1)**I*(-1)**J*M*AA**2/(3.14159**4*OMEGA**2*N*
    $            BB**2)
              G4-G4+16*(-1)**I*(-1)**J*N/(3.14159**4*OMEGA**2*M)
              G7-G7+16*AA/(3.14159**4*BB*OMEGA**2)
              G8-G8+16*(-1)**J*AA/(3.14159**3*N*OMEGA*BB)
              G9-G9+16*(-1)**I/(3.14159**3*M*OMEGA)
 330      CONTINUE
          G5-G4
          G6-G3
     END IF
     IF (TY.EQ.6) GO TO 400
     IF (TY.EQ.7) GO TO 500
     IF (TY.EQ.8) GO TO 600

**************************************************
**************************************************
***      1. ANALYSIS OF SANDWICH PLATES       ***
**************************************************
**************************************************
     WRITE(*,*)'INPUT THE MAGNITUDE OF THE UNIFORM LOAD ( ksi )'
     READ(*,*)UDL
     WRITE(*,*)'INPUT THE THICKNESS OF FACE MATERIAL ( in. )'
```

```
      READ(*,*)TF
      WRITE(*,*)'INPUT THE THICKNESS OF FOAM CORE ( in. )'
      READ(*,*)TC
      WRITE(*,*)'INPUT THE MASS DENSITY OF FOAM CORE ( pcf )'
      READ(*,*)ROC
      WRITE(7,341)UDL,TF,TC,ROC
  341 FORMAT(T10,'THE MAGNITUDE OF THE UNIFORM LOAD =',T50,F12.5,T65,
     $'( ksi )',//,T10,'THE THICKNESS OF FACE MATERIAL =',T50,F12.3,T65,
     $'( in. )',//,T10,'THE THICKNESS OF FOAM CORE =',T50,F12.3,T65,
     $'( in. )',//,T10,'THE MASS DENSITY OF FOAM CORE =',T50,F12.3,T65,
     $'( pcf )',/)

*****************************************************************
***      CALCULATE THE MAXIMUM STRESSES AND DEFLECTION        ***
*****************************************************************
      SD=TC+TF
      D=EF*TF*SD**2/(2.*(1.-NUF**2))
      GC=CG*(ROC/ROS)**G*ES
      S=SD*GC
      DEFL=UDL*AA**4*G1/(16*D)+UDL*AA**2*G2/(4*S)
      SIGMAX=UDL*AA**2*(G3+NUF*G4)/(SD*TF)
      SIGMAY=UDL*AA**2*(G5+NUF*G6)/(SD*TF)
      TAUXY=UDL*AA**2*(1-NUF)*G7/(SD*TF)
      TAUZX=UDL*AA*G8/SD
      TAUYZ=UDL*AA*G9/SD
      WRITE(*,346)SIGMAX,SIGMAY,TAUXY,TAUZX,TAUYZ,DEFL
      WRITE(7,346)SIGMAX,SIGMAY,TAUXY,TAUZX,TAUYZ,DEFL
  346 FORMAT(T10,'THE MAXIMUM STRESSES IN THE FACE MATERIAL :',//,
     $T15,'THE MAXIMUM STRESS SIGMAX (SIGMAR) =',T50,F12.4,T65,'ksi',//,
     $T15,'THE MAXIMUM STRESS SIGMAY (SIGMAT) =',T50,F12.4,T65,'ksi',//,
     $T15,'THE MAXIMUM STRESS TAUXY (TAURT) =',T50,F12.4,T65,'ksi',//,
     $T10,'THE MAXIMUM STRESSES IN THE FOAM CORE :',//,
     $T15,'THE MAXIMUM STRESS TAUZX (TAUZR) =',T50,F12.4,T65,'ksi',//,
     $T15,'THE MAXIMUM STRESS TAUYZ (TAUTZ) =',T50,F12.4,T65,'ksi',//,
     $T10,'THE MAXIMUM DEFLECTION =',T50,F12.4,T65,'in.')

*************************************************
***      JUDGE THE STRENGTH FAILURE MODE      ***
*************************************************
      PFY=YF*TC*TF/(AA**2*(G3+NUF*G4))
      PFW=AFA*TC*TF*(ROC/ROS)**(2*A/3.)/(AA**2*(G3+NUF*G4))
      PCS=C4*(ROC/ROS)**B*YS*TC/(AA*G8)
      FAIL=3
      IF(PFY.LT.PFW) THEN
           IF (PFY.LT.PCS) FAIL=1
      ELSE IF (PFW.LE.PFY) THEN
           IF (PFW.LT.PCS) FAIL=2
      END IF
      IF (FAIL.EQ.1) THEN
           WRITE(*,363)
           WRITE(7,363)
           IF ((PFY-UDL).GT.0) THEN
                WRITE(*,361)
                WRITE(7,361)
           ELSE IF ((PFY-UDL).LE.0) THEN
                WRITE(*,362)
                WRITE(7,362)
           END IF
      ELSE IF (FAIL.EQ.2) THEN
           WRITE(*,364)
```

```
      WRITE(7,364)
      IF ((PFW-UDL).GT.0) THEN
           WRITE(*,361)
           WRITE(7,361)
      ELSE IF ((PFW-UDL).LE.0) THEN
           WRITE(*,362)
           WRITE(7,362)
      END IF
  ELSE IF (FAIL.EQ.3) THEN
      WRITE(*,365)
      WRITE(7,365)
      IF ((PCS-UDL).GT.0) THEN
           WRITE(*,361)
           WRITE(7,361)
      ELSE IF ((PCS-UDL).LE.0) THEN
           WRITE(*,362)
           WRITE(7,362)
      END IF
  END IF
  GO TO 1000
361 FORMAT(T10,'THE SANDWICH PLATE UNDER LOADING IS SAFE',/)
362 FORMAT(T10,'THE SANDWICH PLATE UNDER LOADING IS NOT SAFE',/)
363 FORMAT(/,T10,'THE FAILURE MODE IS FACE YIELDING',/)
364 FORMAT(/,T10,'THE FAILURE MODE IS FACE WRINKLING',/)
365 FORMAT(/,T10,'THE FAILURE MODE IS CORE SHEAR YIELDING',/)

*************************************************************************
*************************************************************************
***      2. MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH PLATE     ***
*************************************************************************
*************************************************************************

****************************************************
**      INPUT THE REQUIRED DESIGN STIFFNESS      ***
****************************************************
400 WRITE(*,*)'INPUT THE REQUIRED DESIGN STIFFNESS ( ksi/in )'
    READ(*,*)STIFF
    WRITE(7,401)STIFF
401 FORMAT(T10,'THE REQUIRED DESIGN STIFFNESS =',T50,F12.5,T65,
   $'( ksi/in )',/)

****************************************************
*      CALCULATE THE OPTIMAL DESIGN VALUES       ***
****************************************************
    ROC=((G+1)**2*(G-1)**2*G2**3*ROS*EF*(STIFF*AA)**2/
   $(256*CG**3*G*(1-NUF**2)*G1*ROF*ES**3))**(1./(3*G-1.))*ROS
    TC=(4**(G+1)*CG*G**G*(G+1)**(G-1)*(1-NUF**2)**G*G1**G*ROF**G*ES*
   $(STIFF*AA)**(G-1)/((G-1)**(2*G)*G2*ROS**G*EF**G))**(1./(3*G-1.))
   $*AA/2.
    TF=((G**2-1)**(G+1)*(1-NUF**2)**(G-1)*G1**(G-1)*G2**2*ROS**(2*G)*
   $EF**(1-G)*(STIFF*AA)**(G+1)/(2**(13*G+1)*CG**2*G**(2*G)*ROF**(2*G)
   $*ES**2))**(1./(3*G-1.))*4*AA
    IF (CONFI.LT.3) WEIGHT=(2*TF*ROF+TC*ROC)*3.14*RCP**2/1728000.
    IF (CONFI.GE.3) WEIGHT=(2*TF*ROF+TC*ROC)*AA*BB/1728000.
    WRITE(*,402)TF,TC,ROC,WEIGHT
    WRITE(7,402)TF,TC,ROC,WEIGHT
402 FORMAT(//,T10,'THE OPTIMAL DESIGN VALUES :',//,
   $T15,'THE OPTIMAL THICKNESS OF FACE MATERIAL =',T55,F12.4,
   $T70,'in.',//,T15,'THE OPTIMAL THICKNESS OF CORE MATERIAL =',T55,
   $F12.4,T70,'in.',//,T15,'THE OPTIMAL MASS DENSITY OF FOAM =',T55,
```

```
     $F12.4,T70,'pcf',//,T15,'THE MINIMUM WEIGHT OF SANDWICH PLATE =',
     $T55,F12.4,T70,'kips',/)
      GO TO 1000

************************************************************************
***     3. MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS       ***
************************************************************************

****************************************************
***     INPUT THE REQUIRED DESIGN STRENGTH      ***
****************************************************
  500 WRITE(*,*)'INPUT THE REQUIRED UNIFORM LOADING ( psi )'
      READ(*,*)STREN
      WRITE(7,551)STREN
      STREN=STREN/1000.
  551 FORMAT(T10,'THE REQUIRED UNIFORM LOADING =',T50,F12.4,T65,'psi',/)

*****************************************************
***     CALCULATE THE OPTIMAL DESIGN VALUES      ***
*****************************************************

*******  FY/FW/CS FAILURE DESIGN ******
      TC=STREN*AA*G8*(YF/AFA)**(-1.5*B/A)/(YS*C4)
      TF=STREN*AA**2.*(G3+NUF*G4)/(YF*TC)
      ROC=(YF/AFA)**(1.5/A)*ROS
      IF (CONFI.LT.3) WEIGHT=(2*ROF*TF+ROC*TC)*3.14*RCP**2/1728000.
      IF (CONFI.GE.3) WEIGHT=(2*ROF*TF+ROC*TC)*AA*BB/1728000.
      FAIL=4
      COEFF=(YF/AFA)**((6*B-3)/(2.*A))*2*ROF*YS**2*C4**2*(G3+NUF*G4)
      STR1=COEFF/(G8**2*ROS*YF)
      COEFF=(YF/AFA)**((6*B-2*A-3)/(2.*A))*(C4*YS)**2*ROF*2*(G3+NUF*G4)
      STR2=COEFF*(2*A-3*B)/(ROS*(3.-3.*B)*G8**2*AFA)
      COEFF=(YF/AFA)**((6*B-3)/(2.*A))*(C4*YS)**2*B*2*ROF*(G3+NUF*G4)
      STR3=COEFF/(ROS*(B-1)*G8**2*YF)
******  FW/FY FAILURE DESIGN   ******
      IF (STREN.LE.STR1) THEN
         COEFF=2*ROF*STREN*AA**2*AFA**(1.5/A)*(G3+NUF*G4)/ROS
         TC1=(COEFF/(YF**(1+(1.5/A))))**0.5
         TF1=STREN*AA**2*(G3+NUF*G4)/(YF*TC1)
         ROC1=(YF/AFA)**(1.5/A)*ROS
         IF (CONFI.LT.3) W1=(2*TF1*ROF+TC1*ROC1)*3.14*RCP**2/1728000.
         IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
         IF (W1.LT.WEIGHT) THEN
            TF=TF1
            TC=TC1
            ROC=ROC1
            WEIGHT=W1
            FAIL=1
         END IF
      END IF
******  FW/CS FAILURE DESIGN   ******
      IF (STREN.LE.STR2) THEN
         COEFF=(STREN*AA*G8/(C4*YS))**((2*A+3)/(3.*B))*AFA
         COEFF=COEFF*ROS*(3-3*B)/(2.*ROF*(2*A-3*B))
         TC1=(COEFF/(STREN*AA**2*(G3+NUF*G4)))**(3*B/(2.*A-6.*B+3.))
         ROC1=(STREN*AA*G8/(C4*YS*TC1))**(1./B)*ROS
         TF1=STREN*AA**2*(G3+NUF*G4)/(AFA*(ROC1/ROS)**(2*A/3.)*TC1)
         IF (CONFI.LT.3) W1=(2*TF1*ROF+TC1*ROC1)*3.14*RCP**2/1728000.
         IF (CONFI.GE.3) W1=(2*TF1*ROF+TC1*ROC1)*AA*BB/1728000.
         IF (W1.LT.WEIGHT) THEN
```

```
              TF=TF1
              TC=TC1
              ROC=ROC1
              WEIGHT=W1
              FAIL=2
          END IF
      END IF
****** FY/CS FAILURE DESIGN ******
      IF (STREN.GE.STR3) THEN
          COEFF=2*B*ROF*(STREN*AA)**((B-1)/B)*AA*(G3+NUF*G4)/YF
          TC1=((C4*YS/G8)**(1./B)*COEFF/(ROS*(B-1)))**(B/(2.*B-1.))
          TF1=STREN*AA**2*(G3+NUF*G4)/(YF*TC1)
          ROC1=(STREN*AA*G8/(C4*YS*TC1))**(1./B)*ROS
          IF (CONFI.LT.3) W1=(2*TF1*ROF+TC1*ROC1)*3.14*RCP**2/1728000.
          IF (CONFI.GE.3) W1=(2*TF1*ROF+TC1*ROC1)*AA*BB/1728000.
          IF (W1.LT.WEIGHT) THEN
              TF=TF1
              TC=TC1
              ROC=ROC1
              WEIGHT=W1
              FAIL=3
          END IF
      END IF
      WRITE(*,560)TC,TF,ROC,WEIGHT
      WRITE(7,560)TC,TF,ROC,WEIGHT
      IF (FAIL.EQ.1) WRITE(7,561)
      IF (FAIL.EQ.2) WRITE(7,562)
      IF (FAIL.EQ.3) WRITE(7,563)
      IF (FAIL.EQ.4) WRITE(7,564)
      GO TO 1000
  560 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUES :',//,T15,
     $'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',//,T15,
     $'THE MINIMUM WEIGHT OF SANDWICH PLATE =',T55,F12.4,T70,'kips',/)
  561 FORMAT(T15,'FY/FW FAILURE DESIGN',/)
  562 FORMAT(T15,'FW/CS FAILURE DESIGN',/)
  563 FORMAT(T15,'FY/CS FAILURE DESIGN',/)
  564 FORMAT(T15,'FY/FW/CS FAILURE DESIGN',/)

*********************************************************
*********************************************************
***     4. MINIMUM WEIGHT DESIGN FOR STIFFNESS        ***
***        AND STRENGTH IN SANDWICH PLATES            ***
*********************************************************
*********************************************************

*********************************************
***     INPUT THE DESIGN PARAMETERS      ***
*********************************************
  600 WRITE(*,*)'INPUT THE REQUIRED UNIFORM LOADING ( ksi )'
      READ(*,*)P
      WRITE(*,*)'INPUT THE DESIGN DEFLECTION ( in )'
      READ(*,*)DELTA
      WRITE(7,671)P,DELTA
  671 FORMAT(T10,'THE REQUIRED UNIFORM LOADING =',T50,F12.4,T65,'kips',
     $//,T10,'THE DESIGN DEFLECTION =',T50,F12.4,T65,'in.',/)

 ***************************************************
 **     CALCULATE THE OPTIMAL DESIGN VALUES      ***
```

```
************************************************************

***       S+FY FAILURE DESIGN       ***
      RCS=(YF/AFA)**(1.5/A)*ROS
      CRIT=8*DELTA*EF*P*(G3+NUF*G4)**2/((1-NUF**2)*G1*YF**2*1000.)
      TF1=CRIT
      WEIGHT=1000000.
      FAIL=1
      WRITE(*,*)'THE PROGRAM IS RUNNING. PLEASE WAIT!'
      DO 673 I=1,999
          TC1=P*AA**2*(G3+NUF*G4)/(YF*TF1)
          COEFF=((DELTA/P)-AA**4*(1-NUF**2)*G1/(8*EF*TF1*TC1**2))**(-1)
          ROC1=(COEFF*AA**2*G2/(4*CG*TC1*ES))**(1./G)*ROS
          IF (CONFI.LT.3) W1=(2*ROF*TF1+ROC1*TC1)*3.14*RCP**2/1728000.
          IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
          IF (ROC1.GE.RCS) THEN
              IF (W1.LE.WEIGHT) THEN
                  TC=TC1
                  TF=TF1
                  ROC=ROC1
                  WEIGHT=W1
              END IF
          END IF
          TF1=TF1+CRIT
  673 CONTINUE

***       S+FW FAILURE DESIGN       ***
      CRIT=RCS/1000.
      ROC1=CRIT
      DO 674 I=1,999
          COEFF=(ROC1/ROS)**(2*A/3.)*AA**2*AFA*G1*(1-NUF**2)/8.
          TC1=COEFF/(DELTA*EF*(G3+NUF*G4))+P*AA**2*G2/(CG*4.*ES*DELTA*
     $        (ROC1/ROS)**G)
          TF1=P*AA**2*(G3+NUF*G4)*(ROC1/ROS)**(-2*A/3.)/(AFA*TC1)
          IF (CONFI.LT.3) W1=(2*ROF*TF1+ROC1*TC1)*3.14*RCP**2/1728000.
          IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
          TL=C4*YS*(G3+NUF*G4)*(ROC1/ROS)**(B-2*A/3.)/(AFA*G8)
          IF ((TF1/AA).LE.TL) THEN
              IF (W1.LE.WEIGHT) THEN
                  TC=TC1
                  TF=TF1
                  ROC=ROC1
                  WEIGHT=W1
                  FAIL=2
              END IF
          END IF
          ROC1=ROC1+CRIT
  674 CONTINUE

***       S+FY+FW FAILURE DESIGN       ***
      ROC1=(YF/AFA)**(1.5/A)*ROS
      COEFF=AA**2*YF*G1*(1-NUF**2)/(8*DELTA*EF*(G3+NUF*G4))
      TC1=COEFF+P*AA**2*G2*(YF/AFA)**(-1.5*G/A)/(4*CG*ES*DELTA)
      TF1=P*AA**2*(G3+NUF*G4)/(YF*TC1)
      IF (CONFI.LT.3) W1=(2*ROF*TF1+ROC1*TC1)*3.14*RCP**2/1728000.
      IF (CONFI.GE.3) W1=(2*ROF*TF1+ROC1*TC1)*AA*BB/1728000.
      IF (W1.LE.WEIGHT) THEN
          TC=TC1
          TF=TF1
          ROC=ROC1
```

```
         WEIGHT=W1
         FAIL=3
      END IF

      WRITE(*,680)TC,TF,ROC,WEIGHT
      WRITE(7,680)TC,TF,ROC,WEIGHT
      IF (FAIL.EQ.1) WRITE(7,681)
      IF (FAIL.EQ.2) WRITE(7,682)
      IF (FAIL.EQ.3) WRITE(7,683)
  680 FORMAT(/,T10,'THE OPTIMAL DESIGN VALUE :',//,T15,
     $'THE OPTIMAL CORE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL FACE THICKNESS =',T55,F12.4,T70,'in.',//,T15,
     $'THE OPTIMAL MASS DENSITY OF FOAM =',T55,F12.4,T70,'pcf',//,T15,
     $'THE MINIMUM WEIGHT OF SANDWICH PLATE =',T55,F12.4,T70,'kips',/)
  681 FORMAT(T15,'STIFFNESS/FY FAILURE DESIGN',/)
  682 FORMAT(T15,'STIFFNESS/FW FAILURE DESIGN',/)
  683 FORMAT(T15,'STIFFNESS/FY/FW FAILURE DESIGN',/)

 1000 STOP
      END
```

ANALYSIS OF SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM = 2.000 (in.)

THE SPAN OF THE SANDWICH BEAM = 30.000 (in.)

THE MASS DENSITY OF CORE MATERIAL = 4.000 (pcf)

THE THICKNESS OF FACE MATERIAL = .050 (in.)

THE THICKNESS OF FOAM CORE = 4.000 (in.)

THE MAGNITUDE OF CONCENTRATED LOAD = .010 (kips)

THE LOCATION OF CONCENTRATED LOAD = 15.000 (in.)

THE CRITICAL BENDING AND SHEAR STRESSES :

Z (in)	SIGMAC (ksi)	TAUC (ksi)
.000	.000000	.000518
.100	.000002	.000518
.200	.000003	.000518
.300	.000005	.000518
.400	[illegible]	.000518
.500	[illegible]	[illegible]

.600	[illegible]	[illegible]
.700	.000011	.000618
.800	.000013	.000618
.900	.000014	.000618
1.000	.000016	.000617
1.100	.000017	.000617
1.200	.000019	.000617
1.300	.000020	.000617
1.400	.000022	.000617
1.500	.000024	.000617
1.600	.000025	.000617
1.700	.000027	.000616
1.800	.000028	.000616
1.900	.000030	.000616
2.000	.000031	.000616

Z (in)	SIGMAF (ksi)	TAUF (ksi)
2.000	.182482	.000616
2.003	.182710	.000585
2.005	.182938	.000555
2.008	.183166	.000524
2.010	.183394	.000494
2.013	.183622	.000463
2.015	.183850	.000433
2.018	.184078	.000402
2.020	.184307	.000371
2.023	.184535	.000341
2.025	.184763	.000310
2.028	.184991	.000279
2.030	.185219	.000248
2.033	.185447	.000217
2.035	.185675	.000186
2.038	.185903	.000155
2.040	.186131	.000124
2.043	.186359	.000093
2.045	.186588	.000062
2.048	.186816	.000031
2.050	.187044	.000000

THE MAXIMUM DEFLECTION = .035319 (in.)

THE FAILURE MODE IS FACE YIELDING

THE SANDWICH BEAM UNDER LOADING IS SAFE

MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM = 2.000 (in.)

THE SPAN OF THE SANDWICH BEAM = 30.000 (in.)

THE REQUIRED DESIGN STRENGTH
PER UNIT WIDTH AND LENGTH = 4.0000 psi

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL CORE THICKNESS = 2.8892 in.

THE OPTIMAL FACE THICKNESS = .0250 in.

THE OPTIMAL MASS DENSITY OF FOAM = 2.9150 pcf

THE MINIMUM WEIGHT OF SANDWICH BEAM = .0006 kips

FY/FW FAILURE DESIGN

MINIMUM WEIGHT DESIGN FOR STIFFNESS IN SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL =	10150.000	(ksi)
THE YIELD STRENGTH OF FACE MATERIAL =	12.470	(ksi)
THE MASS DENSITY OF FACE MATERIAL =	168.570	(pcf)
THE ELASTIC MODULUS OF SOLID FOAM =	232.000	(ksi)
THE YIELD STRENGTH OF SOLID FOAM =	18.415	(ksi)
THE MASS DENSITY OF SOLID FOAM =	75.000	(pcf)
THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.130	
THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.710	
THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF FOAM CORE =	.400	
THE POWER CONSTANT FOR SEAR MODULUS OF FOAM CORE =	2.000	
THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	.310	
THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	1.520	

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM =	2.000	(in.)
THE SPAN OF THE SANDWICH BEAM =	30.000	(in.)
THE REQUIRED DESIGN STIFFNESS =	.50000	(kips/in)

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL CORE THICKNESS =	2.3633	in.
THE OPTIMAL FACE THICKNESS =	.0149	in.
THE OPTIMAL MASS DENSITY OF FOAM =	8.4933	pcf
THE MINIMUM WEIGHT OF SANDWICH BEAM =	.0009	kips
THETA OF THE SHEAR LAG CRITERION =	338.9451	

MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SANDWICH BEAMS

THE ELASTIC MODULUS OF FACE MATERIAL =	10150.000	(ksi)
THE YIELD STRENGTH OF FACE MATERIAL =	12.470	(ksi)
THE MASS DENSITY OF FACE MATERIAL =	168.570	(pcf)
THE ELASTIC MODULUS OF SOLID FOAM =	232.000	(ksi)
THE YIELD STRENGTH OF SOLID FOAM =	18.415	(ksi)
THE MASS DENSITY OF SOLID FOAM =	75.000	(pcf)
THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.130	
THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.710	
THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF FOAM CORE =	.400	
THE POWER CONSTANT FOR SEAR MODULUS OF FOAM CORE =	2.000	
THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	.310	
THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	1.520	

SIMPLY-SUPPORTED UNDER CONCENTRATED LOAD

THE WIDTH OF THE SANDWICH BEAM =	2.000	(in.)
THE SPAN OF THE SANDWICH BEAM =	30.000	(in.)
THE REQUIRED DESIGN LOAD =	.2500	kips
THE REQUIRED DESIGN DEFLECTION =	.5000	in.

THE OPTIMAL DESIGN VALUE :

THE OPTIMAL CORE THICKNESS =	2.9965	in.
THE OPTIMAL FACE THICKNESS =	.0251	in.
THE OPTIMAL MASS DENSITY OF FOAM =	6.5763	pcf
THE MINIMUM WEIGHT OF SANDWICH BEAM =	.0010	kips

STIFFNESS/F. FAILURE DESIGN

ANALYSIS OF SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL = 10150.000 (ksi)

THE YIELD STRENGTH OF FACE MATERIAL = 12.470 (ksi)

THE MASS DENSITY OF FACE MATERIAL = 168.570 (pcf)

THE ELASTIC MODULUS OF SOLID FOAM = 232.000 (ksi)

THE YIELD STRENGTH OF SOLID FOAM = 18.415 (ksi)

THE MASS DENSITY OF SOLID FOAM = 75.000 (pcf)

THE PROPORTIONALITY CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.130

THE POWER CONSTANT
FOR ELASTIC MODULUS OF FOAM CORE = 1.710

THE PROPORTIONALITY CONSTANT
FOR SHEAR MODULUS OF FOAM CORE = .400

THE POWER CONSTANT
FOR SEAR MODULUS OF FOAM CORE = 2.000

THE PROPORTIONALITY CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = .310

THE POWER CONSTANT
FOR SHEAR STRENGTH OF FOAM CORE = 1.520

RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL .300

THE LENGTH (X DIRECTION) OF
THE RECTANGULAR PLATE = 200.000 (in.)

THE .WIDTH (Y DIRECTION) OF
THE RECTANGULAR PLATE = 100.000 (in.)

THE MAGNITUDE OF THE UNIFORM LOAD = .00100 (ksi)

THE THICKNESS OF FACE MATERIAL = .100 (in.)

THE THICKNESS OF FOAM CORE = 4.000 (in.)

THE MASS DENSITY OF FOAM CORE = 4.000 (pcf)

THE MAXIMUM STRESSES IN THE FACE MATERIAL :

THE MAXIMUM STRESS SIGMAX (SIGMAR) 1.1300 ksi

THE MAXIMUM STRESS SIGMAY (SIGMAT) 2.4798 ksi

THE MAXIMUM STRESS TAUXY (TAURT) = 1.1264 ksi

THE MAXIMUM STRESSES IN THE FOAM CORE :

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      THE MAXIMUM STRESS TAUCY (TAUCY  =     .0066   KSI
      THE MAXIMUM STRESS TAUCZ (TAUCZ  =     .0111   KSI
THE MAXIMUM DEFLECTION =                     1.1600  in.
THE FAILURE MODE IS CORE SHEAR YIELDING
THE SANDWICH PLATE UNDER LOADING IS SAFE
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MINIMUM WEIGHT DESIGN F[illegible] . STIFFNESS IN SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL =	10150.000	(ksi)
THE YIELD STRENGTH OF FACE MATERIAL =	12.470	(ksi)
THE MASS DENSITY OF FACE MATERIAL =	168.570	(pcf)
THE ELASTIC MODULUS OF SOLID FOAM =	232.000	(ksi)
THE YIELD STRENGTH OF SOLID FOAM =	18.415	(ksi)
THE MASS DENSITY OF SOLID FOAM =	75.000	(pcf)
THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.130	
THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.710	
THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF FOAM CORE =	.400	
THE POWER CONSTANT FOR SEAR MODULUS OF FOAM CORE =	2.000	
THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	.310	
THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	1.520	

RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL	.300	
THE LENGTH (X DIRECTION) OF THE RECTANGULAR PLATE =	200.000	(in.)
THE WIDTH (Y DIRECTION) OF THE RECTANGULAR PLATE =	100.000	(in.)
THE REQUIRED DESIGN STIFFNESS =	.00100	(ksi/in)

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL THICKNESS OF FACE MATERIAL =	.0178	in.
THE OPTIMAL THICKNESS OF CORE MATERIAL =	5.5394	in.
THE OPTIMAL MASS DENSITY OF FOAM =	4.3228	pcf
THE MINIMUM WEIGHT OF SANDWICH PLATE =	.3464	kips

MINIMUM WEIGHT DESIGN FOR STRENGTH IN SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL =	10150.000	(ksi)
THE YIELD STRENGTH OF FACE MATERIAL =	12.470	(ksi)
THE MASS DENSITY OF FACE MATERIAL =	168.570	(pcf)
THE ELASTIC MODULUS OF SOLID FOAM =	232.000	(ksi)
THE YIELD STRENGTH OF SOLID FOAM =	18.415	(ksi)
THE MASS DENSITY OF SOLID FOAM =	75.000	(pcf)
THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.130	
THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.710	
THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF FOAM CORE =	.400	
THE POWER CONSTANT FOR SEAR MODULUS OF FOAM CORE =	2.000	
THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	.310	
THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	1.520	

RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL	.300	
THE LENGTH (X DIRECTION) OF THE RECTANGULAR PLATE =	200.000	(in.)
THE WIDTH (Y DIRECTION) OF THE RECTANGULAR PLATE =	100.000	(in.)
THE REQUIRED UNIFORM LOADING =	1.0000	psi

THE OPTIMAL DESIGN VALUES :

THE OPTIMAL CORE THICKNESS =	2.0729	in.
THE OPTIMAL FACE THICKNESS =	.0179	in.
THE OPTIMAL MASS DENSITY OF FOAM =	2.9150	pcf
THE MINIMUM WEIGHT OF SANDWICH PLATE =	.1399	kips

FY/FW FAILURE DESIGN

MINIMUM WEIGHT DESIGN FOR STIFFNESS AND STRENGTH IN SANDWICH PLATES

THE ELASTIC MODULUS OF FACE MATERIAL =	10150.000	(ksi)
THE YIELD STRENGTH OF FACE MATERIAL =	12.470	(ksi)
THE MASS DENSITY OF FACE MATERIAL =	168.570	(pcf)
THE ELASTIC MODULUS OF SOLID FOAM =	232.000	(ksi)
THE YIELD STRENGTH OF SOLID FOAM =	18.415	(ksi)
THE MASS DENSITY OF SOLID FOAM =	75.000	(pcf)
THE PROPORTIONALITY CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.130	
THE POWER CONSTANT FOR ELASTIC MODULUS OF FOAM CORE =	1.710	
THE PROPORTIONALITY CONSTANT FOR SHEAR MODULUS OF FOAM CORE =	.400	
THE POWER CONSTANT FOR SEAR MODULUS OF FOAM CORE =	2.000	
THE PROPORTIONALITY CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	.310	
THE POWER CONSTANT FOR SHEAR STRENGTH OF FOAM CORE =	1.520	

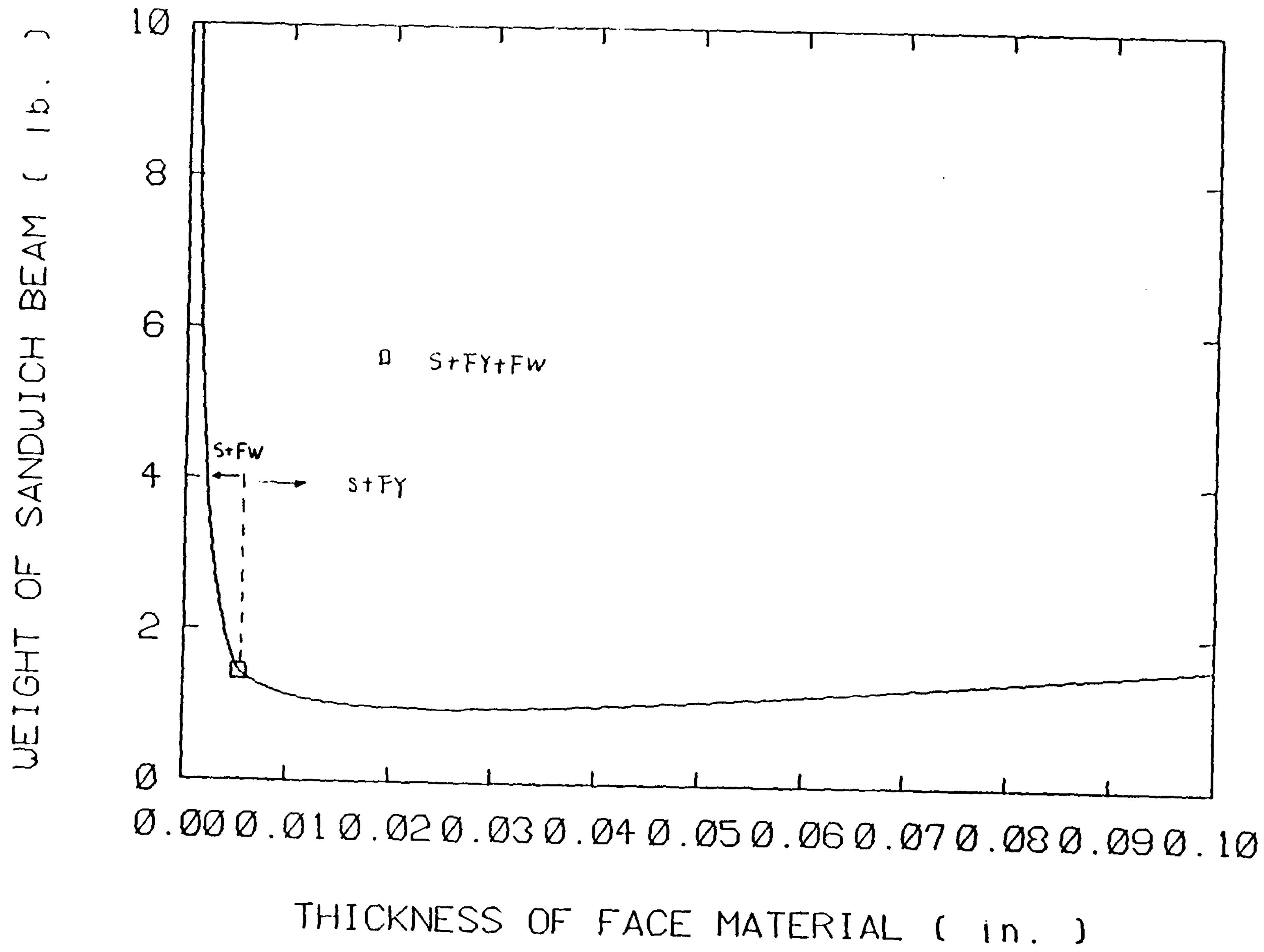
RECTANGULAR PLATE, SIMPLY-SUPPORTED UNDER UNIFORM LOAD

THE POISSON'S RATIO OF THE FACE MATERIAL	.300	
THE LENGTH (X DIRECTION) OF THE RECTANGULAR PLATE =	200.000	(in.)
THE WIDTH (Y DIRECTION) OF THE RECTANGULAR PLATE =	100.000	(in.)
THE REQUIRED UNIFORM LOADING =	.0010	ksi
THE DESIGN DEFLECTION =	1.0000	in.

THE OPTIMAL DESIGN VALUE :

THE OPTIMAL CORE THICKNESS =	10.1207	in.
THE OPTIMAL FACE THICKNESS =	.0037	in.
THE OPTIMAL MASS DENSITY OF FOAM =	3.6316	pcf
THE MINIMUM WEIGHT OF SANDWICH PLATE =	.4397	kips

STIFFNESS/FY FAILURE DESIGN


10
8
6
4
2
Ø
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Ø.04
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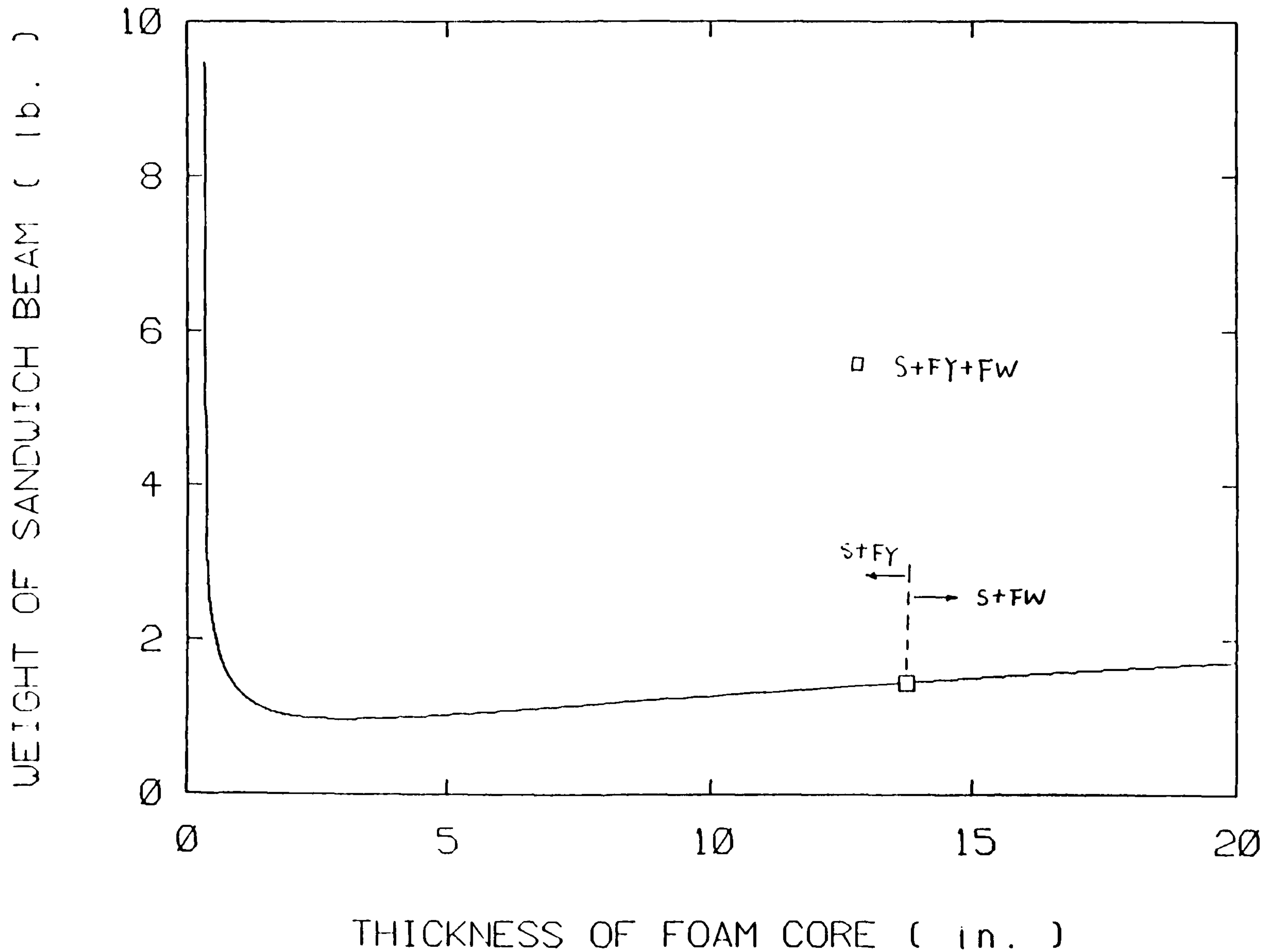
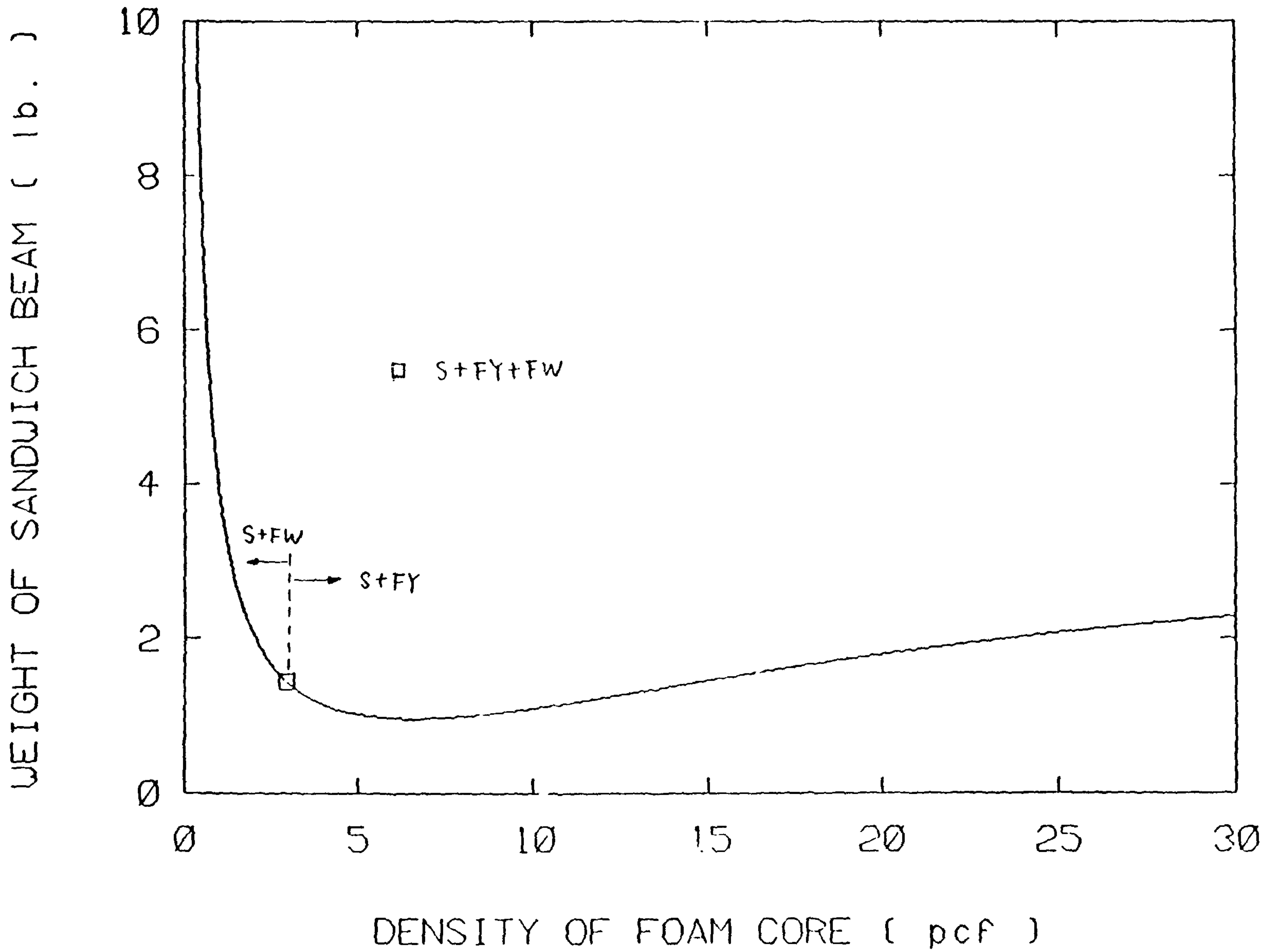
Ø.09
Ø.10
S+FY+FW
S+FW
S+FY
WEIGHT OF SANDWICH BEAM (lb.)
THICKNESS OF FACE MATERIAL (in.)



WEIGHT OF SANDWICH BEAM (lb.)
10
8
6
4
2
Ø
5
1Ø
15
2Ø
S+FY+FW
S+FY
S+FW
THICKNESS OF FOAM CORE (in.)


WEIGHT OF SANDWICH BEAM (lb.)
10
8
6
4
2
0
0
5
10
15
20
25
30
DENSITY OF FOAM CORE (pcf)
S+FY+FW
S+FW
S+FY